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The proceedings of two related conferences which brought together educators, psychologists, and subject-matter specialists to deliberate on the relationship of cognitive studies and curriculum development are reported. Professor Jean Piaget, (a great Swiss scientists and educator) served as chief consultant at the conferences.

The first part consists of translations of Professor Piaget's four major addresses on the cognitive development of children. This same area of cognitive studies is discussed in Part II in the individual reports of various psychologists. Part III consists of presentations by representatives of eleven curriculum projects. All of these reports discuss the basic cognitive process as it is seen in each field. The fields represented are biology, mathematics, English, social studies, elementary science, and psychology.

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PIAGET REDISCOVERED

A Report of the Conference on
Cognitive Studies and Curriculum Development
March 1964

Richard E. Ripple and Verne N. Rockcastle (editors)

School of Education
Cornell University

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A report of the Jean Piaget conferences at
Cornell University and the University of California
supported jointly by the National Science Foundation and
the United States Office of Education

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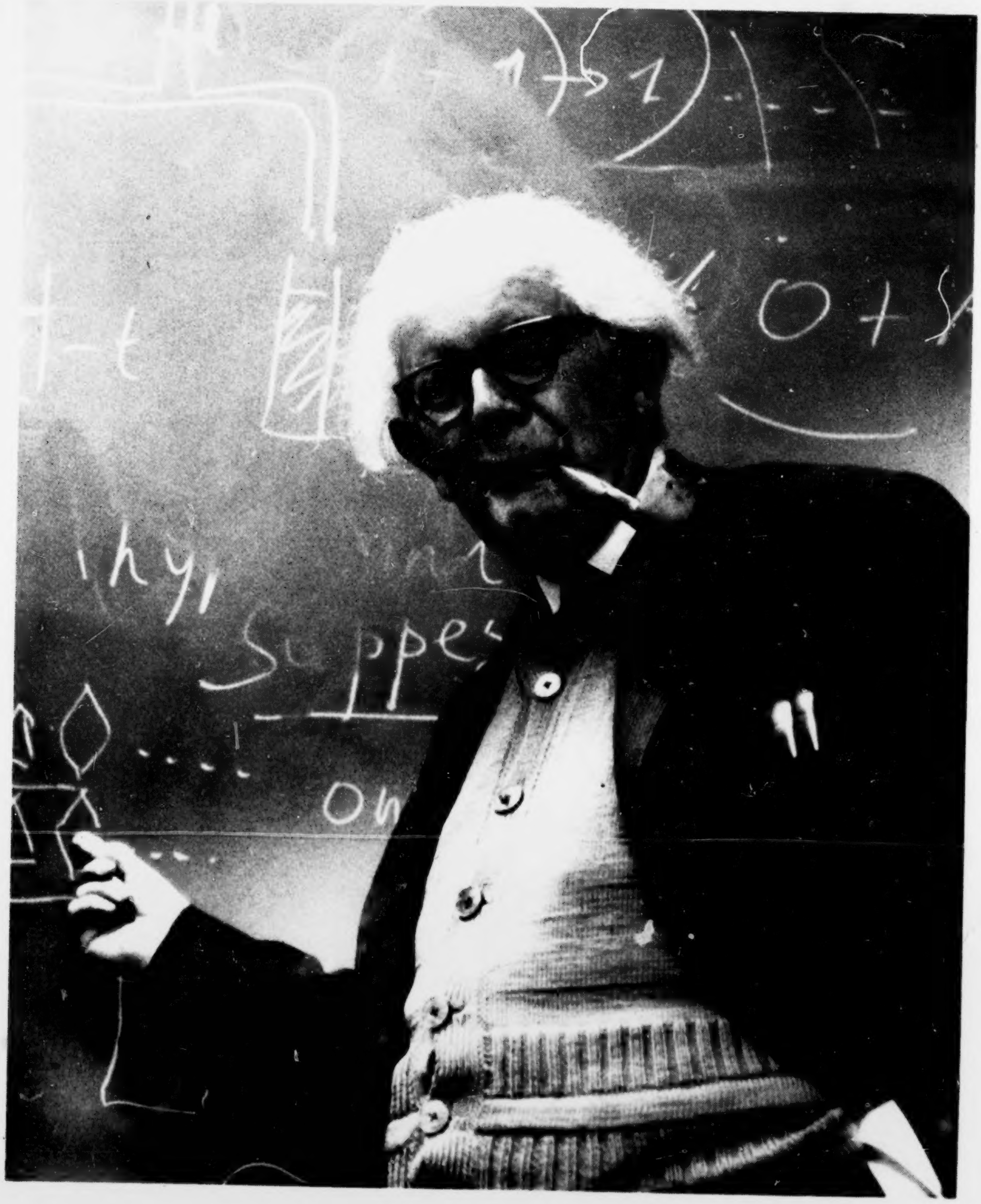

"The accent must be on auto-regulation, on active assimilation - the accent must be on the activity of the subject. Failing this there is no possible didactic or pedagogy which significantly transforms the subject."

Jean Piaget
Ithaca, 1964

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PREFACE

From March 11 to March 13, 1964 some 50 educators, psychologists, and subject-matter specialists met at Cornell University to deliberate on the relationship of cognitive studies and curriculum development. From March 16 to March 18, 1964 an equivalent number of different people with similar credentials replicated the deliberations at the University of California, Berkeley. Professor Jean Piaget served as chief consultant at both conferences. In this publication, based on the proceedings of the conferences, no attempt has been made to follow the chronology of presentations. Instead, Piaget's four major addresses are presented in Part I. Part II consists of presentations by psychologists primarily interested in the study of cognitive development in children. Part III consists of presentations by representatives of various curriculum projects.

In addition to the papers presented, the actual proceedings of the conferences included post-paper discussion, conversation, and interaction among the participants. Unfortunately, these post-paper sessions did not lend themselves to capture by tape or type. Further, the papers themselves vary in the sense that some of the contributors presented their remarks informally and spontaneously while others offered remarks prepared in advance. Thus, for example, some papers are documented; others are not. In preparing this report the general procedure was to send the contributor a transcript of his taped remarks for editing. Thus the papers represent an edited version of either informal or prepared comments.

The conferences were originally conceived as an inquiry into the implications of recent investigations of children's cognitive development for the science curriculum. It soon became apparent that these implications applied to the entire curriculum.

Traditionally, the curriculum has had three bases--the needs of society, the structure of subject matter, and the nature of the developing child. Considerable attention has been devoted recently to examining the structure of subject matter as the basis for curriculum development--evidence by Bruner's bold hypothesis that any subject can be taught effectively in some intellectually honest form to any child at any state of development. Most, if not all, of the major curriculum reform projects have taken the logic (or structure) of the subject matter as a point of departure rather than psychological learning theory or studies of cognitive development. This point is made abundantly clear, for example, in Jeremy Kilpatrick's paper on the SMSG Program included in this report. Further, many of the curriculum reform projects have as a major goal the acceleration of learning, to wit, Bruner's " . . . instruction in scientific ideas, even at the elementary level, need not follow slavishly the natural course of cognitive development in the child. It can also lead intellectual development by providing challenging but usable opportunities for the child to forge ahead in his development."

The revival of interest in the work of Jean Piaget on cognitive development in children has served as a leveling agent to the aspirations of curriculum reformers bent on ignoring children's cognitive development in the name of acceleration. Piaget has invoked the theme of Whitehead's "rhythm of education." To be sure, the lyric no longer runs to Whitehead's Romance, Precision, and Generalisation but the refrain is familiar--different subjects and modes of study should be undertaken by pupils at fitting times when they have reached the proper stage of mental development. In 1922 Whitehead questioned whether " . . . this obvious truth has been handled in educational practice with due attention to the psychology of the pupils." In 1964 Piaget raises the same question for different reasons and with different implications.

Dewey has written, " . . . there are those who see no alternative between forcing the child from without, or leaving him entirely alone. Seeing no alternative some choose one mode, some another. Both fall into the same fundamental error. Both fail to see that development is a definite process having its own law which can be fulfilled only when adequate and normal conditions are provided." Hopefully, one of the contributions of these proceedings is to clarify the alternatives. It is clear that Piaget might speak of the curriculum as the Prophet speaks of the teacher, "If he is indeed wise he does not bid you enter the house of his wisdom, but rather leads you to the threshhold of your own mind."

R.E.R.
V.N.R.

Ithaca
August, 1964

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The following is a list of those people who attended the conferences at Cornell University and the University of California:

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The success of any grand venture is seldom due to the efforts of a single individual. So it was with the Piaget Conference. To Jean Piaget himself goes the largest measure of gratitude for making the conference a success. His willingness to participate, to put himself entirely at the disposal of the conferees during his visit, and the zest with which he entered into the spirit of the sessions set the tone for the whole conference.

To Philip Johnson of Cornell must go credit for proposing the conference and submitting plans for it to the N.S.F. and the U. S. Office of Education. His vast experience and his friendly advice were freely and gratefully used.

A proposal is effective only as it is implemented. Richard Paulson of the National Science Foundation and Francis Ianni of the U. S. Office of Education both realized the value of such a conference and pushed for its financial support. Without their dedication to the support of such undertakings, the conference would not have been realized. Their efforts are deeply appreciated by all concerned.

The many details of organizing the Berkeley Conference were ably handled by Abraham Fischler of the University of California, assisted by Mrs. Mabel Gardner. Only to an insider, does the importance of their contribution become apparent.

Thanks is due both Dean Frederick Stutz of the Cornell School of Education and to Dean Theodore L. Reller of the School of Education at Berkeley for clearing administrative hurdles and assisting in the smooth running of the conference. Their top-level support was most appreciated.

To Lynne Perrin, Secretary in the Cornell School of Education, goes a special note of thanks for her careful attention to details of correspondence, accounting, and the many other facets of running a bilingual, bi-campus conference.

Even with all these dedicated efforts, the conference still owes a great deal of its success to the grand contribution of Eleanor Duckworth of Educational Services, Inc. Her precise, perceptive translation of Piaget's remarks was, next to Piaget himself, the factor most responsible for the effectiveness of each session.

Finally, to Richard Ripple of Cornell goes a sincere expression of gratitude for his professional editing of the psychological contributions in the report. The editing of a bilingual report was not an easy task, but he helped make it a pleasant one.

Verne N. Rockcastle
Conference Director
October, 1964

From The Beginning . . . .

V. N. Rockcastle
Cornell University

How does one get a great scientist such as Piaget to come to Cornell -- or to Berkeley? To answer that question, to show how the conference on cognitive studies evolved, and to give the reader a few personal impressions of Piaget, the following brief account is given.

The happy combination of a Cornell study involving cognitive structures in children, and of my being in Europe on sabbatic leave, suggested to Professor Philip Johnson of Cornell that perhaps I might pay a call on Piaget and explore the possibility of his coming to the United States for some sort of conference or lecture tour. So it was that on May 31, 1963, a call was paid to Jean Piaget at his home, 7 Sur Rang, Pinchat, Geneve, Suisse. Expecting a visitor, he stood at the gate, pipe in his mouth, and that well-known twinkle in his eye. "Bonjour, Monsieur Rockcastle, je suis heureux de vous voir," and I really felt that he meant it. He gave everyone he met that feeling -- except one. That was a nettlesome reporter whom Piaget dispatched with finesse. Piaget can be visibly annoyed, but not without reason.

In the hour that ensued, Piaget must have chuckled to himself many times, for my French was quite unpolished. However, I took heart in the fact that at least I tried to speak his language; he never did try to speak mine. He disclaimed any proficiency in spoken English except for four phrases: "How do you do?" "Very happy to meet you." "I enjoyed your paper." "What did you say your name was?"

When asked about the possibility of a visit to the United States, Piaget was pleasantly agreeable -- if the proper dates, places, and financial arrangements could be made. Then the talk turned to sedums, for Piaget is an expert on those plants. One could hardly pay him a visit without becoming aware of his deep interest in the genus Sedum. They grew in his study and in his garden. The request for a visit to the United States was obviously enhanced by the possibility of some informal conferences with fellow botanists, and especially by the possibility of adding new species to his already sizable collection. Then I ran out of French. Piaget bade a warm and friendly, "Au revoir, Monsieur," and I returned down the hill to Geneve.

Early in the fall of 1963, Phil Johnson drew up a proposal for submission to the National Science Foundation. It was proposed that Piaget be brought to this country as the chief resource person for a conference on cognitive studies and their relation to the science curriculum. After initial contacts with the N.S.F., it was suggested that the U. S. Office of Education be brought into the picture and the scope of the conference widened to include other areas of the curriculum besides science. With this in mind, a final proposal was submitted to the N.S.F., and a corollary proposal to the U. S. Office of Education requesting Piaget's involvement in a two-coast conference, the first half of which would be held at Cornell, and the second half at Berkeley.

The Berkeley campus was selected because of its willingness to participate, and because the dates of the conference fit in well with the campus calendar. Fortunately for us all, Professor Abraham Fischler of the University of California at Berkeley agreed to head up the West Coast Conference. While we at Cornell were engaged in all the preliminary proposal work, and in clearing the way for Piaget to come to the country, Abe Fischler was setting up the conference at Berkeley so that all details on that coast would be cleared and would not involve the Cornell staff.

It was agreed that I should head up the over-all conference, with Professor Philip Johnson acting in an advisory capacity, having drawn up the original proposal. Letters were sent to leaders in various fields of education including science, mathematics, psychology, English, social studies, and curriculum development per se. As soon as any declination was received, another letter went out to a well qualified educational leader. Soon after the proposals were approved by the N.S.F. and the U. S. Office of Education, a list of approximately forty participants for each conference was finalized.

Translators were obtained for both English-French, and French-English, but were used little. Piaget, when looking over the list of participants at the Cornell conference, noticed with pleasure that Eleanor Duckworth of Educational Services, Inc., was going to attend. She had studied with Piaget and knew both him and his theories well. With little urging she agreed to translate Piaget's lectures for the conference. It soon was apparent that Eleanor Duckworth was a real key to the success of the Cornell conference. She was outstanding not only in her interpretation of Piaget's complex phraseology, but in her fielding and translating of the questions directed at Piaget at the close of each of his lectures. There was not any question but that she should translate at Berkeley as well. Again, the success of the conference was due in large measure to her superb translations. Her Piaget Rediscovered is included in this report for your perusal.

Although few of us had any personal contact with Piaget prior to the conferences, those who attended came to have the deepest and warmest regard for him both as a scientist and as a person. His sense of humor throughout the conference was a sort of international glue that flavored his lectures and punctuated his informal conversation. To sit at the table with him during a meal was not only an intellectual pleasure but a pure social delight.

Piaget was completely unsophisticated in spite of his international stature. We could hardly believe it when he came prepared for two weeks' stay with only his "serviette" and a small Swissair bag. An American would have had at least two large suitcases. When Piaget left Berkeley, he had his serviette, the small Swissair bag, and a third, larger bag crammed with botanical specimens. "Where did you get that bag?" we asked. "I had it in one of the others," he replied.

The impressions that he left with me after two weeks in conference, walking to and from buildings, eating breakfast, lunch and dinner together, and chatting informally in small groups, are these:

1. Piaget understands much more English than he lets on! (This may let him creep mouse-like into side conversations.)
2. He is annoyed more by pomp than by simplicity.
3. His sense of humor is superb. He is amused by many situations that pass unnoticed before a less penetrating eye.
4. He shuns the spotlight except when it bears on (a) the developmental psychology of children, and (b) plant life in general and the genus Sedum in particular.
5. His most valued physical characteristic is the twinkle in his eye. It is almost never absent -- except when he suspects a fraud.
6. He takes SUGAR in his coffee -- mostly sugar, diluted with a little coffee!
7. Without his beret and his pipe he just wouldn't be Piaget!
8. In his pipe he smokes a little tobacco, but mostly matches.
9. He has the secret of traveling so far with so little luggage!

PIAGET REDISCOVERED

Eleanor Duckworth

Educational Services Incorporated

The author, Eleanor Duckworth, is a former student of Piaget's at the Institute of Genetic Epistemology in Geneva, Switzerland. She served as Piaget's translator at both the Cornell and California Conferences. In "Piaget Rediscovered" Miss Duckworth has summarized Piaget's contributions at the conferences with an emphasis on the implications of his approach for educational practice.

Everybody in education realizes that Piaget is saying something that is relevant to the teaching of children. For the most part he is understood to be underestimating the value of teaching. He is understood to be saying something like this: Children go through certain stages of intellectual development from birth through adolescence. These stages materialize, fully constructed, when their time has come, and there is little we can do to advance them. What we must do in education is to realize the limits of children's understanding at certain ages, and plan our teaching so it falls within these limits.

In two recent conferences, one at Cornell, one at Berkeley, Piaget made clear that the implications of his psychology for education are a good deal more fecund than this. In fact, the only one of these statements that he would support is that children go through certain stages of intellectual development. Contrary to the view most often attributed to him, he maintains that good pedagogy can have an effect on this development.

I will start with the essentials of Piaget's theory of intellectual development, as presented at these conferences, and then go on to some implications for education.

Development of intellectual capacity goes through a number of stages whose order is constant, but whose time of appearance may vary both with the individual and with the society. Each new level of development is a new coherence, a new structuring of elements which until that time have not been systematically related to each other.

Piaget discussed four factors contributing to this development - nervous maturation, encounters with experience, social transmission, and equilibration or auto-regulation. While the first three do indeed play a role, Piaget finds each of them insufficient in itself. His findings lead him to conclude that an individual's intellectual development is a process of equilibration, where the individual himself is the active motor and coordinator of his own development.

What the first three factors have in common is that the individual is passive. Something is done to him - his physiological system matures, or he is presented with physical or linguistic material to absorb. But intellectual development is not this passive. Piaget finds it necessary to call upon the factor of the individual's own activity. An individual comes to see the world as coherent, as structured, to the extent that he acts upon the world, transforms it, and succeeds in coordinating these actions and transformations.

Development proceeds as partial understandings are revised, broadened, and related to one another. Piaget's model for this is one of auto-regulation to attain even broader and more stable equilibrium in the individual's dealing with his world.

As far as education is concerned, the chief outcome of this theory of intellectual development is a plea that children be allowed to do their own learning. Piaget is not saying that intellectual development proceeds at its own pace no matter what you try to do. He is saying that what schools usually try to do is ineffectual. You cannot further understanding in a child simply by talking to him. Good pedagogy must involve presenting the child with situations in which he himself experiments, in the broadest sense of that term - trying things out to see what happens, manipulating things, manipulating symbols, posing questions and seeking his own answers, reconciling what he finds one time with what he finds at another, comparing his findings with those of other children.

Beyond this general implication, Piaget does not claim to be an educator. During the course of the two conferences he made no single discourse on pedagogy. But he made a number of points which I have gathered together here. Most of them are not new ideas; but it seems to me that it is of importance, somehow, to realize that this is what he is saying.

I shall start with comments on one or two teaching practices often associated with Piaget's name, because of some relationships to his research. One is the head-on attack on a specific notion in a precise and limited way. This is the type of attack engaged in by psychological experimenters, in trying to teach four- and five-year-olds, for example, that the amount of liquid stays the same when poured into a glass of a different shape. (In Piaget's own research, when a child asserts that the same amount of liquid is conserved, this is taken as an indication of a certain structure of mental operations. For this reason, performance on this task is an important indicator of intellectual level.)

Piaget sees little sense in intensive specific training on tasks like this one. His feeling is that no learning of significance will take place. Even if the child does manage to learn something about this situation, the learning is not likely to have a general effect on his level of understanding.

But notice that he is not thereby saying that a young child's mental structure cannot be touched. He is only saying that this type of specific attack is rather trivial. Modifying a child's effective set of mental operations depends on a much wider, longer-lasting and fundamental approach, which involves all of the child's activity.

Piaget amplified this point about the importance of investigative activity in general in reply to a question on cross-cultural comparisons. Montreal psychologists, using Piaget's material as tests, found children in Martinique to be delayed several years over children in Montreal. Similarly, there is a significant delay of children in Iranian villages over children in Iranian cities. Piaget was asked what factors in the adult societies might account for these differences.

In reply, he first pointed out that the schools in Martinique follow the same curriculum as the schools in France, so that scholastic preparation was not likely to account for the difference. Then he quoted the psychologist who had done the research in Martinique, who pointed out that the climate is fine, agriculture flourishes, and living poses few problems. There seems to be little call for questioning and struggling for solutions - in general, little call for either physical or intellectual activity. Piaget speculated that this could be the significant factor.

Another pedagogical approach often associated with Piaget's name has to do with teaching the "structure" of a subject matter area. This has been associated with him because of the importance that mental structures play in his psychological theory. The word "structure" is seized upon as the link.

The pedagogical idea is that children should be taught the unifying themes of a subject matter area, after which they will be able to relate individual items to this general structure. (This seems to be what Bruner often means by 'teaching the structure' in The Process of Education.) Commenting on this procedure, Piaget made the following statement:

"The question comes up whether to teach the structure, or to present the child with situations where he is active and creates the structures himself... The goal in education is not to increase the amount of knowledge, but to create the possibilities for a child to invent and discover. When we teach too fast, we keep the child from inventing and discovering himself...Teaching means creating situations where structures can be discovered; it does not mean transmitting structures which may be assimilated at nothing other than a verbal level."

Piaget addressed two remarks to problems of teacher training. The first is that adults, as well as children, can learn better by doing things than by being told about them. He was talking about teachers in training, when he said, "If they read about it, it will be deformed, as is all learning that is not the result of the subject's own activity."

The second is that prospective teachers ought to spend some time questioning children in a one-to-one situation, in order to realize how hard it is to understand what children mean, and even more, how hard it is to make oneself understood by children. Each prospective teacher should work on an original investigation to find out what children think about some problem - and thus be forced to phrase the problem and establish communication with a number of different children. Facing the difficulties of this type of research will have a sobering effect on a teacher who thinks he is talking successfully to a whole class of children at once.

Permit me one other point of psychological theory, as context for another of Piaget's remarks. Piaget sees the process of equilibration as a process of balance between assimilation and accommodation in a biological sense. An individual assimilates the world - which comes down to saying he sees it in his own way. But sometimes something presents itself in such a way that he cannot assimilate it into his view of things, so he must change his view - he must accommodate if he wants to incorporate this new item.

The question arose in this conference as to whether school situations could lead a child to accommodate wrongly - that is, to change his ideas on the wrong basis. Piaget replied: "This is a very interesting question. This is a big danger of school - false accommodation which satisfies a child because it agrees with a verbal formula he has been given. This is a false equilibrium which satisfies a child by accommodating to words - to authority and not to objects as they present themselves to him....A teacher would do better not to correct a child's schemas, but to provide situations so he will correct them himself."

Here are a few other remarks at random:

# "Experience is always necessary for intellectual development....But I fear that we may fall into the illusion that being submitted to an experience (a demonstration) is sufficient for a subject to disengage the structure involved. But more than this is required. The subject must be active, must transform things, and find the structure of his own actions on the objects."

# "When I say "active", I mean it in two senses. One is acting on material things. But the other means doing things in social collaboration, in a group effort. This leads to a critical frame of mind, where children must communicate with each other. This is an essential factor in intellectual development. Cooperation is indeed co-operation."

(The role of social interaction is important in Piaget's theory of development. A characteristic phenomenon in intellectual difficulties of pre-school children is that they have difficulty conceiving of any point of view other than their own. Coming to an awareness that another child sees something differently from the way he sees it plays an important role in bringing a child to accommodate, to rebuild his point of view, and come closer to a coherent operational structure.)

"The best idea I have heard from a pedagog at the International Bureau of Education in Geneva was made by a Canadian. He said that in his province they had just decided every class should have two classrooms - one where the teacher is, and one where the teacher isn't."

"The teacher must provide the instruments which the children can use to decide things by themselves. Children themselves must verify, experimentally in physics, deductively in mathematics. A ready-made truth is only a half-truth."

One participant asked what Piaget thought of having children of different ages in a class together. He replied that it might be helpful especially for the older ones. They could be given some responsibility of teaching younger ones. "Nobody knows better than a professor that the best way to learn something is to teach it."

"Yes, the element of surprise is an essential motor in education and in scientific research in general. What distinguishes a good scientist is that he is amazed by things which seem natural to others. Surprise plays an important role; we might well try to develop an aptitude for surprise."

"Words are probably not a short-cut to a better understanding..... The level of understanding seems to modify the language that is used, rather than vice versa. . . .Mainly, language serves to translate what is already understood; or else language may even present a danger if it is used to introduce an idea which is not yet accessible."

"The principle goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done - men who are creative, inventive, and discoverers. The second goal of education is to form minds which can be critical, can verify, and not accept everything they are offered. The great danger today is of slogans, collective opinions, ready-made trends of thought. We have to be able to resist individually, to criticize, to distinguish between what is proven and what is not. So we need pupils who are active, who learn early to find out by themselves, partly by their own spontaneous activity and partly through material we set up for them; who learn early to tell what is verifiable and what is simply the first idea to come to them."

PART I

COGNITIVE DEVELOPMENT IN CHILDREN: THE PIAGET PAPERS

DEVELOPMENT AND LEARNING

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In his opening remarks Piaget makes a distinction between development and learning--development being a spontaneous process tied to embryogenesis, learning being provoked by external situations. He proceeds to discuss the concept of an operation as an interiorized action linked to other operations in a structure. Four stages of development are enumerated--sensori-motor, pre-operational, concrete operations, and formal operations. Factors explaining the development of one structure of operations from another are discussed--maturation, experience, social transmission, and equilibration. Equilibration is defended as the most fundamental factor. Commenting on the inadequacy of the stimulus-response approach to understanding learning, Piaget presents evidence negating the effectiveness of external reinforcement in hastening the development of operational structures. These operational structures can be learned only if one bases the learning on simpler, more elementary structures-- only if there is a natural relationship and development of structures. The learning of these structures is held to follow the same basic laws as does their natural development, i.e., learning is subordinated to development. Piaget concludes that the fundamental relation involved in development and learning is assimilation, not association.

My dear colleagues, I am very concerned about what to say to you, because I don't know if I shall accomplish the end that has been assigned to me. But I've been told that the important thing is not what you say, but the discussion which follows, and the answers to questions you are asked. So this morning I shall simply give a general introduction of a few ideas which seem to me to be important for the subject of this conference.

First I would like to make clear the difference between two problems: the problem of development in general, and the problem of learning. I think these problems are very different, although some people do not make this distinction.

The development of knowledge is a spontaneous process, tied to the whole process of embryogenesis. Embryogenesis concerns the development of the body, but it concerns as well the development of the nervous system, and the development of mental functions. In the case of the development of knowledge in children, embryogenesis ends only in adulthood. It is a total developmental process which we must re-situate in its general biological and psychological context. In other words, development is a process which concerns the totality of the structures of knowledge.

Learning presents the opposite case. In general, learning is provoked by situations -- provoked by a psychological experimenter; or by a teacher, with respect to some didactic point; or by an external situation. It is provoked, in general, as opposed to spontaneous. In addition, it is a limited process -- limited to a single problem, or to a single structure.

So I think that development explains learning, and this opinion is contrary to the widely held opinion that development is a sum of discrete learning experiences. For some psychologists development is reduced to a series of specific learned items, and development is thus the sum, the cumulation of this series of specific items. I think this is an atomistic view which deforms the real state of things. In reality, development is the essential process and each element of learning occurs as a function of total development, rather than being an element which explains development. I shall begin, then, with a first part dealing with development, and I shall talk about learning in the second part.

To understand the development of knowledge, we must start with an idea which seems central to me -- the idea of an operation. Knowledge is not a copy of reality. To know an object, to know an event, is not simply to look at it and make a mental copy, or image, of it. To know an object is to act on it. To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed. An operation is thus the essence of knowledge; it is an interiorised action which modifies the object of knowledge. For instance, an operation would consist of joining objects in a class, to construct a classification. Or an operation would consist of ordering, or putting things in a series. Or an operation would consist of counting, or of measuring. In other words, it is a set of actions modifying the object, and enabling the knower to get at the structures of the transformation.

An operation is an interiorised action. But in addition, it is a reversible action; that is, it can take place in both directions, for instance, adding or subtracting, joining or separating. So it is a particular type of action which makes up logical structures.

Above all, an operation is never isolated. It is always linked to other operations, and as a result it is always a part of a total structure. For instance, a logical class does not exist in isolation; what exists is the total structure of classification. An asymmetrical relation does not exist in isolation. Seriation is the natural, basic operational structure. A number does not exist in isolation. What exists is the series of numbers, which constitute a structure, an exceedingly rich structure whose various properties have been revealed by mathematicians.

These operational structures are what seem to me to constitute the basis of knowledge, the natural psychological reality, in terms of which we must understand the development of knowledge. And the central problem of development is to understand the formation, elaboration, organization, and functioning of these structures.

I should like to review the stages of development of these structures, not in any detail, but simply as a reminder. I shall distinguish four main stages. The first is a sensory-motor, pre-verbal stage, lasting approximately the first 18 months of life. During this stage is developed the practical knowledge which constitutes the substructure of later representational knowledge. An example is the construction of the schema of the permanent object. For an infant, during the first months, an object has no permanence. When it disappears from the perceptual field it no longer exists. No attempt is made to find it again. Later, the infant will try to find it, and he will find it by localizing it spatially. Consequently, along with the construction of the permanent object there comes the construction of practical, or sensory-motor, space. There is similarly the construction of temporal succession, and of elementary sensory-motor causality. In other words, there is a series of structures which are indispensable for the structures of later representational thought.

In a second stage, we have pre-operational representation -- the beginnings of language, of the symbolic function, and therefore of thought, or representation. But at the level of representational thought, there must now be a reconstruction of all that was developed on the sensory-motor level. That is, the sensory-motor actions are not immediately translated into operations. In fact, during all this second period of pre-operational representations, there are as yet no operations as I defined this term a moment ago. Specifically, there is as yet no conservation which is the psychological criterion of the presence of reversible operations. For example, if we pour liquid from one glass to another of a different shape, the pre-operational child will think there is more in one than in the other. In the absence of operational reversibility, there is no conservation of quantity.

In a third stage the first operations appear, but I call these concrete operations because they operate on objects, and not yet on verbally expressed hypotheses. For example, there are the operations of classification, ordering, the construction of the idea of number, spatial and temporal operations, and all the fundamental operations of elementary logic of classes and relations, of elementary mathematics, of elementary geometry and even of elementary physics.

Finally, in the fourth stage, these operations are surpassed as the child reaches the level of what I call formal or hypothetic-deductive operations; that is, he can now reason on hypotheses, and not only on objects. He constructs new operations, operations of propositional logic, and not simply the operations of classes, relations, and numbers. He attains new structures which are on the one hand combinatorial, corresponding to what mathematicians call lattices; on the other hand, more complicated group structures. At the level of concrete operations, the operations apply within an immediate neighborhood: for instance, classification by successive inclusions. At the level of the combinatorial, however, the groups are much more mobile. These, then, are the four stages which we identify, whose formation we shall now attempt to explain.

What factors can be called upon to explain the development from one set of structures to another? It seems to me that there are four main factors: first of all, maturation, in the sense of Gesell, since this development is a continuation of the embryogenesis; second, the role of experience of the effects of the physical environment on the structures of intelligence; third, social transmission in the broad sense (linguistic transmission, education, etc.); and fourth, a factor which is too often neglected but one which seems to me fundamental and even the principal factor. I shall call this the factor of equilibration or if you prefer it, of self-regulation.

Let us start with the first factor, maturation. One might think that these stages are simply a reflection of an interior maturation of the nervous system, following the hypotheses of Gesell, for example. Well, maturation certainly does play an indispensable role and must not be ignored. It certainly takes part in every transformation that takes place during a child's development. However, this first factor is insufficient in itself. First of all, we know practically nothing about the maturation of the nervous system beyond the first months of the child's existence. We know a little bit about it during the first two years but we know very little following this time. But above all, maturation doesn't explain everything, because the average ages at which these stages appear (the average chronological ages) vary a great deal from one society to another. The ordering of these stages is constant and has been found in all the societies studied. It has been found in various countries where psychologists in universities have redone the experiments but it has also been found in African peoples for example, in the children of the Bushmen, and in Iran, both in the villages and in the cities. However, although the order of succession is constant, the chronological ages of these stages varies a great deal. For instance, the ages which we have found in Geneva are not necessarily the ages which you would find in the United States. In Iran, furthermore, in the city of Teheran, they found approximately the same ages as we found in Geneva, but there is a systematic delay of two years in the children in the country. Canadian psychologists who redid our experiments, Monique Laurendeau and Father Adrien Pinard, found once again about the same ages in Montreal. But when they redid the experiments in Martinique, they found a delay of four years in all the experiments and this in spite of the fact that the children in Martinique go to a school set up according to the French system and the French curriculum and attain at the end of this elementary school a certificate of higher primary education. There is then a delay of four years, that is, there are the same stages, but systematically delayed. So you see that these age variations show that maturation does not explain everything.

I shall go on now to the role played by experience. Experience of objects, of physical reality, is obviously a basic factor in the development of cognitive structures. But once again this factor does not explain everything. I can give two reasons for this. The first reason is that some of the concepts which appear at the beginning of the stage of concrete operations are such that I cannot see how they could be drawn from experience. As an example, let us take the conservation of the substance in the case of changing the shape of a ball of plasticene. We give this ball of plasticene to a child who changes its shape into a sausage form and we ask him if there is the same amount of matter, that is, the same amount of substance as there was before. We also ask him if it now has the same weight and thirdly if it now has the same volume. The volume is measured by the displacement of water when we put the ball or the sausage into a glass of water. The findings, which have been the same every time this experiment has been done, show us that first of all there is conservation of the amount of substance. At about eight years old a child will say, "There is the same amount of plasticene." Only later does the child assert that the weight is conserved and still later that the volume is conserved. So I would ask you where the idea of the conservation of substance can come from. What is a constant and invariant substance when it doesn't yet have a constant weight or a constant volume? Through perception you can get at the weight of the ball or the volume of the ball but perception cannot give you an idea of the amount of substance. No experiment, no experience, can show the child that there is the same amount of substance. He can weigh the ball and that would lead to the conservation of weight. He can immerse it in water and that would lead to the conservation of volume. But the notion of substance is attained before either weight or volume. This conservation of substance is simply a logical necessity. The child now understands that when there is a transformation something must be conserved because by reversing the transformation you can come back to the point of departure and once again have the ball. He knows that something is conserved but he doesn't know what. It is not yet the weight, it is not yet the volume; it is simply a logical form -- a logical necessity. There, it seems to me, is an example of a progress in knowledge, a logical necessity for something to be conserved even though no experience can have lead to this notion.

My second objection to the sufficiency of experience as an explanatory factor is that this notion of experience is a very equivocal one. There are, in fact, two kinds of experience which are psychologically very different and this difference is very important from the pedagogical point of view. It is because of the pedagogical importance that I emphasize this distinction. First of all, there is what I shall call physical experience, and secondly, what I shall call logical-mathematical experience.

Physical experience consists of acting upon objects and drawing some knowledge about the objects by abstraction from the objects. For example, to discover that this pipe is heavier than this watch, the child will weigh them both and find the difference in the objects themselves. This is experience in the usual sense of the term -- in the sense used by empiricists. But there is a second type of experience which I shall call logical-mathematical experience where the knowledge is not drawn from the objects, but it is drawn by the actions effected upon the objects. This is not the same thing. When one acts upon objects, the objects are indeed there, but there is also the set of actions which modify the objects.

I shall give you an example of this type of experience. It is a nice example because we have verified it many times in small children under seven years of age, but it is also an example which one of my mathematician friends has related to me about his own childhood, and he dates his mathematical career from this experience. When he was four or five years old -- I don't know exactly how old, but a small child -- he was seated on the ground in his garden and he was counting pebbles. Now to count these pebbles he put them in a row and he counted them one, two, three, up to ten. Then he finished counting them and started to count them in the other direction. He began by the end and once again he found ten. He found this marvelous that there were ten in one direction and ten in the other direction. So he put them in a circle and counted them that way and found ten once again. Then he counted them in the other direction and found ten once more. So he put them in some other direction and found ten once more. So he put them in some other arrangement and kept counting them and kept finding ten. There was the discovery that he made.

Now what indeed did he discover? He did not discover a property of pebbles; he discovered a property of the action of ordering. The pebbles had no order. It was his action which introduced a linear order or a cyclical order, or any kind of an order. He discovered that the sum was independent of the order. The order was the action which he introduced among the pebbles. For the sum the same principle applied. The pebbles had no sum; they were simply in a pile. To make a sum, action was necessary -- the operation of putting together and counting. He found that the sum was independent of the order, in other words, that the action of putting together is independent of the action of ordering. He discovered a property of actions and not a property of pebbles. You may say that it is in the nature of pebbles to let this be done to them and this is true. But it could have been drops of water, and drops of water would not have let this be done to them because two drops of water and two drops of water do not make four drops of water as you know very well. Drops of water then would not let this be done to them, we agree to that.

So it is not the physical property of pebbles which the experience uncovered. It is the properties of the actions carried out on the pebbles and this is quite another form of experience. It is the point of departure of mathematical deduction. The subsequent deduction will consist of interiorizing these actions and then of combining them without needing any pebbles. The mathematician no longer needs his pebbles. He can combine his operations simply with symbols and the point of departure of this mathematical deduction is logical-mathematical experience and this is not at all experience in the sense of the empiricists. It is the beginning of the coordination of actions, but this coordination of actions before the stage of operations needs to be supported by concrete material. Later, this coordination of actions leads to the logical-mathematical structures.

I believe that logic is not a derivative of language. The source of logic is much more profound. It is the total coordination of actions, actions of joining things together, or ordering things, etc. This is what logical-mathematical experience is. It is an experience of the actions of the subject, and not an experience of objects themselves. It is an experience which is necessary before there can be operations. Once the operations have been attained this experience is no longer needed and the coordinations of actions can take place by themselves in the form of deduction and construction for abstract structures.

The third factor is social transmission -- linguistic transmission or educational transmission. This factor, once again, is fundamental. I do not deny the role of any one of these factors; they all play a part. But this factor is insufficient because the child can receive valuable information via language or via education directed by an adult only if he is in a state where he can understand this information. That is, to receive the information he must have a structure which enables him to assimilate this information. This is why you cannot teach higher mathematics to a five-year old. He does not yet have structures which enable him to understand.

I shall take a much simpler example, an example of linguistic transmission. As my very first work in the realm of child psychology, I spent a long time studying the relation between a part and a whole in concrete experience and in language. For example, I used Burt's test employing the sentence, "Some of my flowers are buttercups." The child knows that all buttercups are yellow, so there are three possible conclusions: the whole bouquet is yellow, or part of the bouquet is yellow, or none of the flowers in the bouquet is yellow. I found that up until nine years of age (and this was in Paris, so the children certainly did understand the French language) they replied, "The whole bouquet is yellow or some of my flowers are yellow." Both of those mean the same thing. They did not understand the expression, "some of my flowers." They did not understand this of as a partitive genitive, as the inclusion of some flowers in my flowers. They understood some of my flowers to be my several flowers as if the several flowers and the flowers were confused as one and the same class. So there you have children who until nine years of age heard every day a linguistic structure which implied the inclusion of a sub-class in a class and yet did not understand this structure. It is only when they themselves are in firm possession of this logical structure, when they have constructed it for themselves according to the developmental laws which we shall discuss, that they succeed in understanding correctly the linguistic expression.

I come now to the fourth factor which is added to the three preceding ones but which seems to me to be the fundamental one. This is what I call the factor of equilibration. Since there are already three factors, they must somehow be equilibrated among themselves. That is one reason for bringing in the factor of equilibration. There is a second reason, however, which seems to me to be fundamental. It is that in the act of knowing, the subject is active, and consequently, faced with an external disturbance, he will react in order to compensate and consequently he will tend towards equilibrium. Equilibrium, defined by active compensation, leads to reversibility. Operational reversibility is a model of an equilibrated system where a transformation in one direction is compensated by a transformation in the other direction. Equilibration, as I understand it, is thus an active process. It's a process of self-regulation. I think that this self-regulation is a fundamental factor in development. I use this term in the sense in which it is used in cybernetics, that is, in the sense of processes with feedback and with feedforward, of processes which regulate themselves by a progressive compensation of systems. This process of equilibration takes the form of a succession of levels of equilibrium, of levels which have a certain probability which I shall call a sequential probability, that is, the probabilities are not established a priori. There is a sequence of levels. It is not possible to reach the second level unless equilibrium has been reached at the first level, and the equilibrium of the third level only becomes possible when the equilibrium of the second level has been reached, and so forth. That is, each level is determined as the most probable given that the preceding level has been reached. It is not the most probable at the beginning, but it is the most probable once the preceding level has been reached.

As an example, let us take the development of the idea of conservation in the transformation of the ball of plasticene into the sausage shape. Here you can discern four levels. The most probable at the beginning is for the child to think of only one dimension. Suppose that there is a probability of 0.8, for instance, that the child will focus on the length, and that the width has a probability of 0.2. This would mean that of ten children, eight will focus on the length alone without paying any attention to the width, and two will focus on the width without paying any attention to the length. They will focus only on one dimension or the other. Since the two dimensions are independent at this stage, focusing on both at once would have a probability of only 0.16. That is less than either one of the two. In other words, the most probable in the beginning is to focus only on one dimension and in fact the child will say, "It's longer, so there's more in the sausage." Once he has reached this first level, if you continue to elongate the sausage, there comes a moment when he will say, "No, now it's too thin, so there's less." Now he is thinking about the width, but he forgets the length, so you have come to a second level which becomes the most probable after the first level, but which is not the most probable at the point of departure. Once he has focused on the width, he will come back sooner or later to focus on the length. Here you will have a third level where he will oscillate between width and length and where he will discover that the two are related. When you elongate you make it more thin, and when you make it shorter, you make it thicker. He discovers that the two are solidly related and in discovering this relationship, he will start to think in terms of the transformation and not only in terms of the final configuration. Now he will say that when it gets longer it gets thinner, so it's the same thing. There is more of it in length but less of it in width. When you make it shorter it gets thicker; there's less in length and more in width, so there is compensation -- compensation which defines equilibrium in the sense in which I defined it a moment ago. Consequently, you have operations and conservation. In other words, in the course of these developments you will always find a process of self-regulation which I call equilibration and which seems to me the fundamental factor in the acquisition of logical-mathematical knowledge.

I shall go on now to the second part of my lecture, that is, to deal with the topic of learning. Classically, learning is based on the stimulus-response schema. I think the stimulus-response schema, while I won't say it is false, is in any case entirely incapable of explaining cognitive learning. Why? Because when you think of a stimulus-response schema, you think usually that first of all there is a stimulus and then a response is set off by this stimulus. For my part, I am convinced that the response was there first, if I can express myself in this way. A stimulus is a stimulus only to the extent that it is significant and it becomes significant only to the extent that there is a structure which permits its assimilation, a structure which can integrate this stimulus but which at the same time sets off the response. In other words, I would propose that the stimulus-response schema be written in the circular form -- in the form of a schema or of a structure which is not simply one way. I would propose that above all, between the stimulus and the response there is the organism, the organism and its structures. The stimulus is really a stimulus only when it is assimilated into a structure and it is this structure which sets off the response. Consequently, it is not an exaggeration to say that the response is there first, or if you wish at the beginning there is the structure. Of course we would want to understand how this structure comes to be. I tried to do this earlier by presenting a model of equilibration or self-regulation. Once there is a structure, the stimulus will set off a response, but only by the intermediary of this structure.

I should like to present some facts. We have facts in great number. I shall choose only one or two and I shall choose some facts which our colleague, Smedslund, has gathered. (Smedslund is currently at the Harvard Center for Cognitive Studies.) Smedslund arrived in Geneva a few years ago convinced (he had published this in one of his papers) that the development of the ideas of conservation could be indefinitely accelerated through learning of a stimulus-response type. I invited Smedslund to come to spend a year in Geneva to show us this, to show us that he could accelerate the development of operational conservation. I shall relate only one of his experiments.

During the year that he spent in Geneva he chose to work on the conservation of weight. The conservation of weight is, in fact, easy to study since there is a possible external reinforcement, that is, simply weighing the ball and the sausage on a balance. Then you can study the child's reactions to these external results. Smedslund studied the conservation of weight on the one hand, and on the other hand, he studied the transitivity of weights, that is, the transitivity of equalities if $A = B$ and $B = C$, then $A = C$, or the transitivity of the equalities if A is less than B, and B is less than C, then A is less than C.

As far as conservation is concerned, Smedslund succeeded very easily with five- and six-year-old children in getting them to generalize that weight is conserved when the ball is transformed into a different shape. The child sees the ball transformed into a sausage or into little pieces or into a pancake or into any other form, he weighs it, and he sees that it is always the same thing. He will affirm it will be the same thing, no matter what you do to it; it will come out to be the same weight. Thus Smedslund very easily achieved the conservation of weight by this sort of external reinforcement.

In contrast to this, however, the same method did not succeed in teaching transitivity. The children resisted the notion of transitivity. A child would predict correctly in certain cases but he would make his prediction as a possibility or a probability and not as a certainty. There was never this generalized certainty in the case of transitivity.

So there is the first example, which seems to me very instructive, because in this problem in the conservation of weight there are two aspects. There is the physical aspect and there is the logical-mathematical aspect. Note that Smedslund started his study by establishing that there was a correlation between conservation and transitivity. He began by making a statistical study on the relationships between the spontaneous responses to the questions about conservation and the spontaneous responses to the questions about transitivity, and he found a very significant correlation. But in the learning experiment, he obtained a learning of conservation and not of transitivity. Consequently, he was successful in obtaining learning of what I called earlier physical experience (This is not surprising; it is simply a question of noting facts about objects.) but he was not successful in obtaining a learning in the construction of the logical structure. This doesn't surprise me either, since the logical structure is not the result of physical experience. It cannot be obtained by external reinforcement. The logical structure is reached only through internal equilibration, by self-regulation, and the external reinforcement of seeing the balance did not suffice to establish this logical structure of transitivity.

I could give many other comparable examples, but it seems to me useless to insist upon these negative examples. Now I should like to show that learning is possible in the case of these logical-mathematical structures, but on one condition -- that is, that the structure which you want to teach to the subjects can be supported by simpler, more elementary, logical-mathematical structures. I shall give you an example. It is the example of the conservation of number in the case of one-to-one correspondence. If you give a child seven blue tokens and ask him to put down as many red tokens, there is a preoperational stage where he will put one red one opposite each blue one. But when you spread out the red ones, making them into a longer row, he will say to you, ''Now, there are more red ones than there are blue ones.''

Now how can we accelerate, if you want to accelerate, the acquisition of this conservation of number? Well, you can imagine an analogous structure but in a simpler, more elementary, situation. For example, with Mlle. Inhelder, we have been studying recently the notion of one-to-one correspondence by giving the child two glasses of the same shape and a big pile of beads. The child puts a bead into one glass with one hand and at the same time a bead into the other glass with the other hand. Time after time he repeats this action, a bead into one glass with one hand and at the same time a bead into the other glass with the other hand and he sees that there is always the same amount on each side. Then you hide one of the glasses. You cover it up. He no longer sees this glass but he continues to put one bead into it while putting at the same time one bead into the other glass which he can see. Then you ask him whether the equality has been conserved, whether there is still the same amount in one glass as in the other. Now you will find that very small children, about four years old, don't want to make a prediction. They will say, "So far, it has been the same amount, but now I don't know. I can't see anymore, so I don't know." They do not want to generalize. But the generalization is made from the age of about five and one-half years.

This is in contrast to the case of the red and blue tokens with one row spread out, where it isn't until seven or eight years of age that children will say there are the same number in the two rows. As one example of this generalization, I recall a little boy of five years and nine months who had been adding the beads to the glasses for a little while. Then we asked him whether, if he continued to do this all day and all night and all the next day, there would always be the same amount in the two glasses. The little boy gave this admirable reply, "Once you know, you know for always." In other words, this was recursive reasoning. So here the child does acquire the structure in this specific case. The number is a synthesis of class inclusion and ordering. This synthesis is being favored by the child's own actions. You have set up a situation where there is an iteration of one same action which continues and which is therefore ordered while at the same time being inclusive. You have, so to speak, a localized synthesis of inclusion and ordering which facilitates the construction of the idea of number in this specific case, and there you can find, in effect, an influence of this experience on the other experience. However, this influence is not immediate. We study the generalization from this recursive situation to the other situation where the tokens are laid on the table in rows, and it is not an immediate generalization but it is made possible through intermediaries. In other words, you can find some learning of this structure if you base the learning on simpler structures.

In this same area of the development of numerical structures, the psychologist Joachim Wohlwill, who spent a year at our Institute at Geneva, has also shown that this acquisition can be accelerated through introducing additive operations, which is what we introduced also in the experiment which I just described. Wohlwill introduced them in a different way but he too was able to obtain a certain learning effect. In other words, learning is possible if you base the more complex structure on simpler structures, that is, when there is a natural relationship and development of structures and not simply an external reinforcement.

Now I would like to take a few minutes to conclude what I was saying. My first conclusion is that learning of structures seems to obey the same laws as the natural development of these structures. In other words, learning is subordinated to development and not vice-versa as I said in the introduction. No doubt you will object that some investigators have succeeded in teaching operational structures. But, when I am faced with these facts, I always have three questions which I want to have answered before I am convinced.

The first question is, "Is this learning lasting? What remains two weeks or a month later?" If a structure develops spontaneously, once it has reached a state of equilibrium, it is lasting, it will continue throughout the child's entire life. When you achieve the learning by external reinforcement, is the result lasting or not and what are the conditions necessary for it to be lasting?

The second question is, "How much generalization is possible?" What makes learning interesting is the possibility of transfer of a generalization. When you have brought about some learning, you can always ask whether this is an isolated piece in the midst of the child's mental life, or if it is really a dynamic structure which can lead to generalizations.

Then there is the third question, "In the case of each learning experience what was the operational level of the subject before the experience and what more complex structures has this learning succeeded in achieving?" In other words, we must look at each specific learning experience from the point of view of the spontaneous operations which were present at the outset and the operational level which has been achieved after the learning experience.

My second conclusion is that the fundamental relation involved in all development and all learning is not the relation of association. In the stimulus-response schema, the relation between the response and the stimulus is understood to be one of association. In contrast to this, I think that the fundamental relation is one of assimilation. Assimilation is not the same as association. I shall define assimilation as the integration of any sort of reality into a structure, and it is this assimilation which seems to me fundamental in learning, and which seems to me the fundamental relation from the point of view of pedagogical or didactic applications. All of my remarks today represent the child and the learning subject as active. An operation is an activity. Learning is possible only when there is active assimilation. It is this activity on the part of the subject which seems to me underplayed in the stimulus-response schema. The presentation which I propose puts the emphasis on the idea of self regulation, on assimilation. All the emphasis is placed on the activity of the subject himself, and I think that without this activity there is no possible didactic or pedagogy which significantly transforms the subject.

Finally, and this will be my last concluding remark, I would like to comment on an excellent publication by the psychologist Berlyne. Berlyne spent a year with us in Geneva during which he intended to translate our results on the development of operations into stimulus-response language, specifically into Hull's learning theory. Berlyne published in our series of studies of genetic epistemology a very good article on this comparison between the results of Geneva and Hull's theory. In the same volume, I published a commentary on Berlyne's results. Now the essence of Berlyne's results is this: our findings can very well be translated into Hullian language, but only on condition that two modifications are introduced. Berlyne himself found these modifications quite considerable, but they seemed to him to concern more the conceptualization than the Hullian theory itself. I'm not so sure about that. The two modifications are these. First of all, Berlyne wants to distinguish two sorts of responses in the S-R schema. First, responses in the ordinary, classical sense, which I shall call "copy responses", and secondly, what Berlyne called "transformation responses." Transformation responses consist of transforming one response of the first type into another response of the first type. These transformation responses are what I call operations, and you can see right away that this is a rather serious modification of Hull's conceptualization because here you are introducing an element of transformation and thus of assimilation and no longer the simple association of stimulus-response theory.

The second modification which Berlyne introduces into the stimulus-response language is the introduction of what he calls internal reinforcements. What are these internal reinforcements? They are what I call equilibration or self-regulation. The internal reinforcements are what enable the subject to eliminate contradictions, incompatibilities, and conflicts. All development is composed of momentary conflicts and incompatibilities which must be overcome to reach a higher level of equilibrium. Berlyne calls this elimination of incompatibilities internal reinforcements.

So you see that it is indeed a stimulus-response theory, if you will, but first you add operations and then you add equilibration. That's all we want!

> Editor's note: A brief question and answer period followed Professor Piaget's presentation. The first question related to the fact that the eight-year-old child acquires conservation of substance prior to conservation of weight and volume. The question asked if this didn't contradict the order of emergence of the pre-operational and operational stages. Piaget's response follows:

The conservation of weight and the conservation of volume are not due only to experience. There is also involved a logical framework which is characterized by reversibility and the system of compensations. I am only saying that in the case of weight and volume, weight corresponds to a perception. There is an empirical contact. The same is true of volume. But in the case of substance, I don't see how there can be any perception of substance independent of weight or volume. The strange thing is that this notion of substance comes before the two other notions. Note that in the history of thought, we have the same thing. The first Greek physicists, the pre-socratic philosophers, discovered conservation of substance independently of any experience. I do not believe this is contradictory with the theory of operations. This conservation of substance is simply the affirmation that something must be conserved. The children don't know specifically what is conserved. They know that since the sausage can become a ball again there must be something which is conserved, and saying "substance" is simply a way of translating this logical necessity for conservation. But this logical necessity results directly from the discovery of operations. I do not think that this is contradictory with the theory of development.

Editor's note: The second question was whether or not the development of stages in children's thinking could be accelerated by practice, training, and exercise in perception and memory. Piaget's response follows:

I am not very sure that exercise of perception and memory would be sufficient. I think that we must distinguish within the cognitive function two very different aspects which I shall call the figurative aspect and the operative aspect. The figurative aspect deals with static configurations. In physical reality there are states, and in addition to these there are transformations which lead from one state to another. In cognitive functioning one has the figurative aspects -- for example, perception, imitation, mental imagery, etc.

Secondly, there is the operative aspect, including operations and the actions which lead from one state to another. In children of the higher stages and in adults, the figurative aspects are subordinated to the operative aspects. Any given state is understood to be the result of some transformation and the point of departure for another transformation. But the pre-operational child does not understand transformations. He does not have the operations necessary to understand them so he puts all the emphasis on the static quality of the states. It is because of this, for example, that in the conservation experiments he simply compares the initial state and the final state without being concerned with the transformation.

In exercising perception and memory, I feel that you will reinforce the figurative aspect without touching the operative aspect. Consequently, I'm not sure that this will accelerate the development of cognitive structures. What needs to be reinforced is the operative aspect -- not the analysis of states, but the understanding of transformations.

THE DEVELOPMENT OF MENTAL IMAGERY

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Piaget discusses recent work in Geneva on mental imagery in this paper. He sees mental imagery as being integrally related to the nature of knowing. Two aspects of knowing are differentiated--the figurative aspect and the operative aspect. The figurative aspect deals essentially with fixed states; the operative aspect with transformations leading from one state to another. On the basis of these research studies, Piaget concludes that operations involve more than just imagery. Operations involve transformations which are part of a total structure. The evolution of imagery is directed by intelligence. It is not an internal, autonomous evolution.

I have been asked to speak to you about our most recent work in Geneva. Our work at the moment is of various sorts. Some of us are continuing research on the operations involved in thinking, others of us are dealing with problems of epistemology which are raised by these operations. Other research deals with perception, and finally, some research is concerned with the development of mental imagery, and this is what I would like to speak to you about.

I want to talk about this branch of our research because mental imagery raises the very general question of the nature of knowing. Two quite different aspects of the act of knowing come into play, depending upon whether we are dealing with states or with transformations leading from one state to another. The aspects of knowing which deal essentially with fixed states we shall call the figurative aspects or the figurative function. Examples of this function which deals with static configurations independent of transformations are perception, imitation, and mental imagery about which we shall be speaking later. The aspects which focus on transformations I shall refer to as the operative function. In this we shall include physical actions which transform objects in one way or another, and we shall include operations, that is, interiorized actions which have become reversible and are coordinated with other operations in a structure. These operations also focus on transformations of objects.

In adults, the figurative aspect is subordinated to the operative aspect -- that is, we see each state as the result of a transformation of a previous state and as the point of departure for a transformation which will lead to another state. But, it might be interesting to see whether the operative aspect is the more fundamental one at every age. Specifically we can look at the role that the figurative aspect plays in the thinking of small children before they have established operational structures. For this reason, it is interesting to look at the role played by mental imagery in the thinking of very young children and to follow the evolution of this mental imagery.

So, although the problem which we are going to deal with seems to be a very limited one, its bearing is in reality very general. The general question is, "What does knowing consist of? Is knowing simply a copy of reality, or is it an assimilation of reality to certain structures of intelligence, and in particular to logical-mathematical structures -- that is, to the structures which deal most successfully with these transformations leading from one state to another?"

We shall attack this very concretely by studying mental imagery in certain very specific operational situations. Our method is the following one. We take up again a number of our original experiments on the operations involved in thinking, and specifically, on the notions of conservation, which are the simplest criteria of the presence of operations. But in this case, instead of performing the transformations on the material and then questioning the children about them, we show him the material and outline to him what we are about to do. Then we ask him to predict ahead of time what is going to happen. We ask him to anticipate the transformations by imagining the state which will result from the transformations.

Thus, we are studying mental image as an anticipation of states which have not yet been seen. Then, afterwards, we study the operational reaction of the child to the problem and this enables us to compare the imagery with the operation. Now the specific problem which I would like to discuss is the following one: Does the imagery prepare the way for the operation or, on the contrary, does the image sometimes present an obstacle to the development of the operation? Or is there no relationship at all between the image and the operation?

Let us start with one of our early experiments on the conservation of number. We give the child a certain number of red tokens and ask him to put down just as many blue ones. At a certain level, let's say at five or six years of age, the child will put one blue token opposite each red one and in this way gives the impression that he already has the notion of number -- at least that he has the notion of the operation of one to one correspondence. But now, if we spread out the blue tokens, we find that between the ages of about five and seven the child will think that there are more in the row which has been spread out. If he knows, for example, that there are seven or eight in the shorter row, he will say that there are about nine or ten in the longer row. Then if you ask him to count, he will count and see that there are seven in one row and seven in the other row, but he will nonetheless say that there are more in the longer row. "Yes, there are six there and six there, but there it's longer and there it's shorter, so there are more there anyway." This old experiment raises a curious problem from the point of view of mental imagery, because it seems that nothing would be easier than to understand that the token which had been in this spot has simply been pushed over a bit, but that nothing else has been changed about it. It would seem that to answer this problem correctly, all that would be necessary would be to imagine that the tokens moved a little bit.

Now, let us look at this question from the point of view of an anticipatory image. We have an apparatus in a fan shape with a series of tracks, adjacent tracks. (Figure 1) We put one red token at the top of each of these tracks, and one blue token at the bottom of each track. Each token can move up and down in its own track but can't go across the barrier into another track. Nothing seems simpler than to understand that each one of these tokens can go up to meet the other token in its own track and yet can't go anywhere else, and so that consequently there is the same number of tokens above as below. Well, the extraordinary thing is that this apparatus leads to almost no change in the answers of small children. Small children still say there are more up here because it's longer and there are less down here because it's shorter. So then we say to the little children, "What's going to happen if we push these tokens along the track -- down to the middle, for instance?" The children will say, "Then they'll all be there, and there will be a bit fewer than there were up here, but still a bit more than there are down at the bottom." Then you ask, "What will happen if you push them still farther?" "Well, if you push them right down to the bottom, there will be the same number, and if you push them back up again or if you push one back up, there will once again be more above and fewer below, as before." In other words, the child has no trouble at all in imagining the displacements along the tracks, but what holds his attention is not the displacement which I shall call the longitudinal displacement, but rather the transverse dimension -- the row gets longer or the row gets shorter. That is what strikes him, and the fact that the tokens go along tracks has little importance.

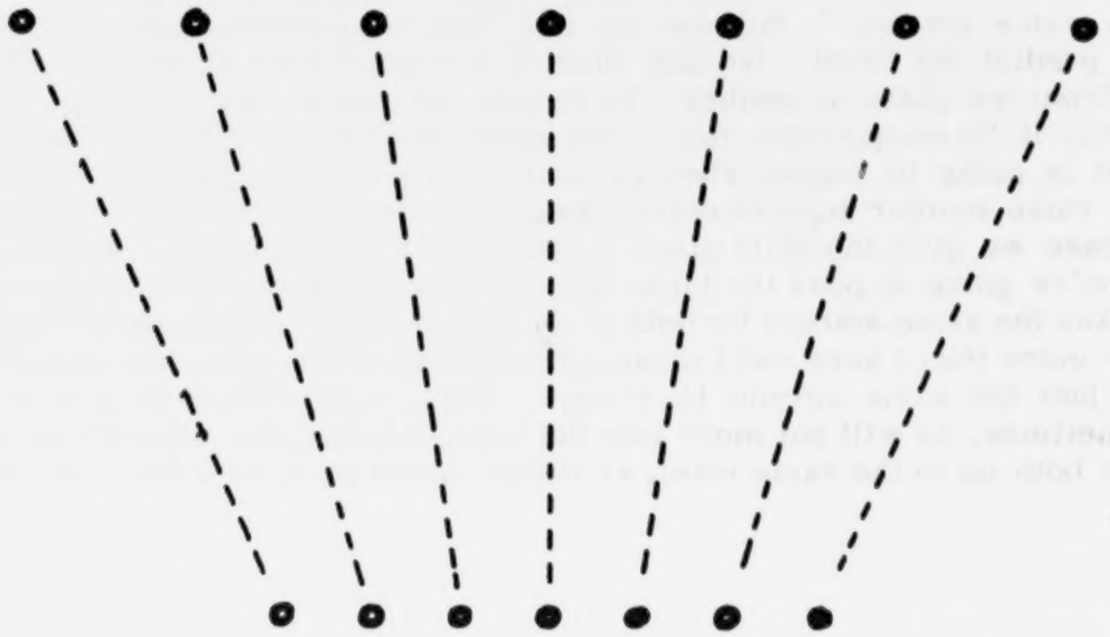

Figure 1

Finally, we tried to simplify the situation again. We attached the tokens mechanically to a bar which we could move behind the apparatus so that all the tokens moved together. We no longer have one token moving at a time, but all of them move together, up or down. Well, we found that in spite of this apparatus, the children reacted in the same way. This made it a little bit easier. There was a difference of a few months in the average age, so that the children would be successful at about six and one-half years old instead of at seven years old. But until six and one-half they would continue to say that when the tokens move down, there become fewer of them, and when they move up, there become more of them. My assistant, who built the apparatus, was certain that in this case all the children would attain a level of conservation of number -- that there would no longer be any problem. He began with his own daughter, who was five years old, and his daughter refused to agree that the number stayed the same. The number got bigger when the bar went up, and smaller when the bar came down, just as if the facilitation of the role of mental imagery played no part at all. I conclude from this experiment that the mental imagery does not seem to help the operation. At the pre-operational level, the imagery focuses only on the transverse dimension. Only when operations enter into play does the child start to pay attention to the longitudinal dimension and start to predict correctly. But it is the operation which is doing the work here, and mental imagery does not seem to have prepared the way.

A second experiment that I would like to talk to you about is the experiment on the non-conservation of a quantity of liquid. If you pour a liquid from one glass, glass A, into another glass which is thinner and taller, glass B, or into glass C which is wider and lower, (Figure 2) the child, up until the age of seven years old, says that the amount of liquid has changed. In glass B he will say there is more because the liquid is now higher, or in glass C there is less because the level is lower. Starting at about seven years old, the child will say that the quantity hasn't changed at all. He will say, "All you've done is to pour it, and that doesn't do anything. There's still the same thing to drink, there's still the same amount." Suppose we see what the children will say if we ask them to predict the level. We ask them to imagine ahead of time the result of pouring from one glass to another. To do this, we present the child with glass A and we fill it three-quarters full. The other glasses are empty. Then we ask him what is going to happen when we pour the water into glass B. At the same time we raise another supplementary question which we have found very useful. In this case we give the child glass A and glass B, both empty, and say to him, "Now you're going to pour the juice into these two glasses, one for you and one for me, and the same amount for both of us, but you must do it evenly. You must not have more than I have and I must not have more than you have -- we've got to have just the same amount to drink." Then we ask him to pour it himself. Now sometimes, he will put more into the thinner glass, but other times he will fill them both up to the same level, as if that meant there was the same amount to drink.

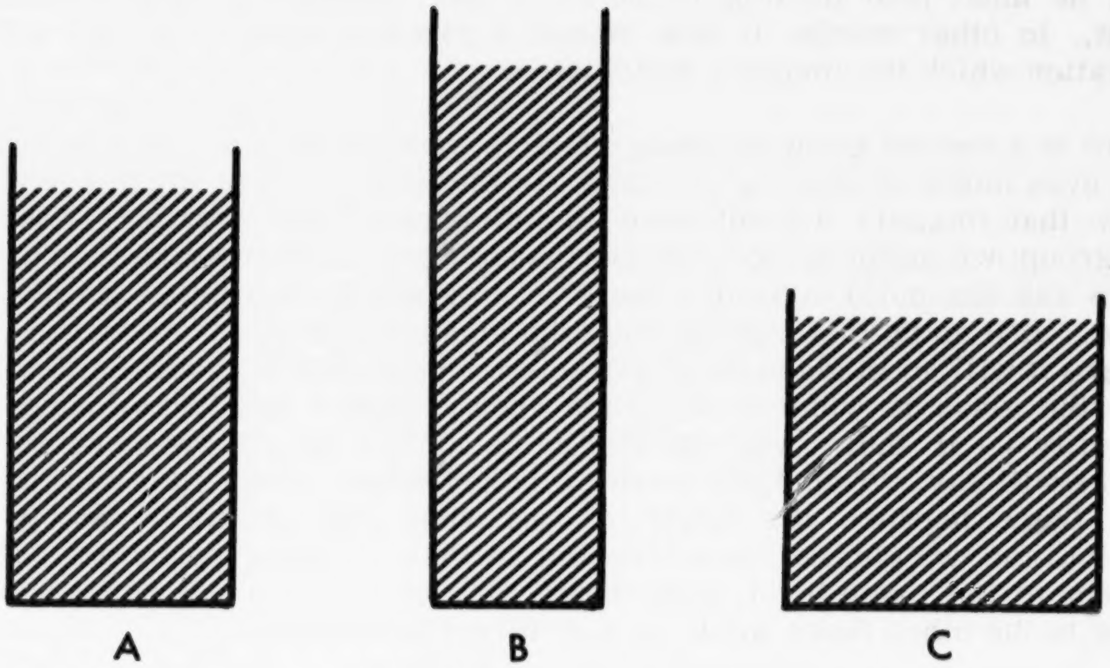

Figure 2

Let us look at the result of the anticipations in the first experiment that I described. Between the ages of five and eight we find three types of reactions. First of all, there is the important group of small children from four to six. Not all the children at this age fall into this group, but most of them do. When we ask them what is going to happen if we pour from glass A into glass B, they will say, "You'll have just the same amount, there will be the same amount to drink." It would seem then that they predict that the amount of liquid will be conserved. Then we ask them how high the water will be in glass B and they will say, "It'll be that high," indicating the same level as in glass A. "It will be that high; it's the same amount. And in glass C, it will be that high," again indicating the same level. "It will always be the same amount." This group, when we ask them to pour the water into the two glasses, to make the same amount in the two glasses, will always fill them up to the same level. In other words, the apparent conservation which they indicated when they said that the amount would not be changed is only a pseudo-conservation because for these children everything is conserved, not only the quantity, but the level, as if the level were the criterion for quantity. We see very well, when they pour the liquid themselves up to the same level in two different shaped glasses, that what they think of conservation of quantity does not correspond to an adequate evaluation of quantity. They are simply judging on the basis of level. They think that everything will be conserved. Then when we pour the liquid and the child sees that in reality it goes higher in glass B, he will say, "Oh no, I made a mistake. Now there's much more drink than there was before." So in fact the quantity is not conserved.

But he will still maintain that in the two glasses where he is to pour the same amount, he must pour them up to the same level in order to make a just apportionment. In other words, it was indeed a pseudo-conservation and not a real conservation which the imagery anticipates.

There is a second group of young subjects, younger than seven years old, who have an even more interesting reaction. In the first group of which I just spoke, you saw that imagery did not have an influence on the operation. Now in this second group, we might be led to believe that imagery does prepare the operation. When we ask the child to predict the level in glass B, he replies correctly. He will say, "It'll go up that high because the glass is thinner." And when you ask him where it will go in glass C, he will answer correctly, "It will be lower down because the glass is wider." But then when you ask him "What's happening to the quantity -- if there will be the same amount or not the same amount to drink" he will say, "There will be more here because it's higher and there will be less there because it's lower." And when you ask him to pour the same amount into the two glasses, he will do just as the preceding group did -- he will pour them to the same level, even though he was able to predict that in pouring from one to the other there would be a different level.

In other words, here the image is simply a result of previous experience, and this is what is interesting. The child has had the occasion to see every day milk, water, coffee etc. being poured from one vessel to another. He has enough empirical data to anticipate the level correctly. But this is not sufficient for conservation. He does not understand that in rising up higher in the thinner glass, what was gained in height was lost in width. He does not understand that there is a system of compensations involving two dimensions. He simply predicts empirically as a result of observations which he has already made. But the imagery here, although it is correct, does not suffice to give rise to the operation. The operation is something other than the image. It supposes a system of transformations, of compensations -- a reversible system, where what is gained in one dimension is lost in another. The operation is not derived directly from the image because there is a delay of one or two years between the two.

Finally, there is a third group of subjects, seven years of age or older, who predict correctly the level of the liquid and who affirm conservation. Their imagery is correct, their operations are also correct, and these two support each other. This is in contrast with the preceding group where the operation did not come out of the imagery -- the imagery was not sufficient to give rise to the operation.

Now I would like to go on very briefly to another conservation experiment. This is the transformation of a ball of plasticene into a sausage shape or any other shape. Here, once again, we found in our original experiments, a level of non-conservation in children younger than seven or eight years. We found that this non-conservation was due to the fact that the little children were reasoning only on the basis of one dimension. They would say, for instance, "You made your ball longer, the sausage is longer, so there is more in it" without taking the thickness into account. Or a few subjects would say, "The sausage is thinner, so there is less in it", without taking the length into account. So it was interesting to find out what their anticipatory image was. Would the small child predict on the basis of only one dimension, or would his imagery be correct and pave the way for the operation, or would it simply be correct independently of the operation? These are the questions which we raised.

We raised, in addition, one other question which turned out to be just as interesting. This was the question of inverse transformation. We gave the child a sausage and asked him to predict how it would look if we made it into a ball. How big would the ball be? Would you get a little ball of the same diameter of the width of the sausage, or would you get a ball of the diameter of the length of the sausage, etc? Those were our questions.

Briefly, we got the following results. The image anticipated by the very small children had the same character as those we have described for the other experiments. When they were presented with a ball and asked to draw a sausage, they drew it as longer, but having the same diameter, or they would show you with their fingers how big the sausage would be and would indicate the same diameter as the ball. Following this there was an intermediary stage where the diameter got a little bit smaller, but not nearly enough, and finally, there was a stage where the anticipations were correct. In the first, earliest stage, naturally there is no conservation. Of course they will say there is more to eat in the sausage than in the ball. In the case of the inverse anticipation, that is, where we started with the sausage, they would predict a ball that was too little, whose diameter was about the width of the initial sausage.

I would like to talk to you about one final experiment before concluding. It is the experiment of conservation of length. We present the child with two sticks of the same length. He satisfies himself that they are the same length by comparing them. Then when they are laid on the table, we push one slightly ahead of the other. The smallest children will tell you that when you pushed one stick out beyond the other one, it became longer, "It's longer because it goes out farther than the other one." That's the fact which we found in our earlier experiments and on which we based these experiments. You can see that there is a problem in this result -- a semantic, linguistic problem -- does the child understand what we want him to answer? When he says that one gets longer because it goes farther, has he understood that we are talking about the total length when we say "long" or has he equated "goes farther" or "farther" with "longer" by a verbal and semantic confusion? As a general phenomenon, all the authors who have not redone our experiments always start their criticisms by asking whether the children really understood what Piaget was asking them. Were they really replying to the question that they were asked? Of course, we take great pains to adapt our language to the child's language, but in this particular case, the question is more serious, because there are, in fact, two notions involved. There is the ordinal notion of farther or nearer -- the order of the points of arrival. And then there is the metric notion of length, that is, the interval between the point of departure and the point of arrival. When the child says it's longer because it goes out beyond, we're not certain whether the child is seeing this as a question on the ordinal relationship or on the metric relationship.

There is one first reinforcement which would tend to support us in our interpretation of the finding, but which is not quite sufficient. This is the following experiment which we did at the same time as the original one. We had an apparatus where there were two roads -- one straight one and one crooked one. Streetcars went along these roads. The experimenter moves his streetcar along the crooked road, and the child along the straight road. The experimenter says, "I'm going to travel along this road, and then you are going to travel along your road exactly the same distance that I did. You are to go over just as much road as I do." These streetcars are represented by little beads and the roads by strings that we can slide the beads along. So I would put my bead on the crooked road, and I would say to the child, "There, I did all this trip," indicating all the turns with my finger, "Now you do just as long a trip on your straight road." (Figure 3) The child then put his bead right underneath mine, saying, "There, I've done a trip just as long." I would say to the child, "Are you really sure? I did all that and you only did that much," and he would answer, "But there I am and there you are -- it's exactly the same trip."

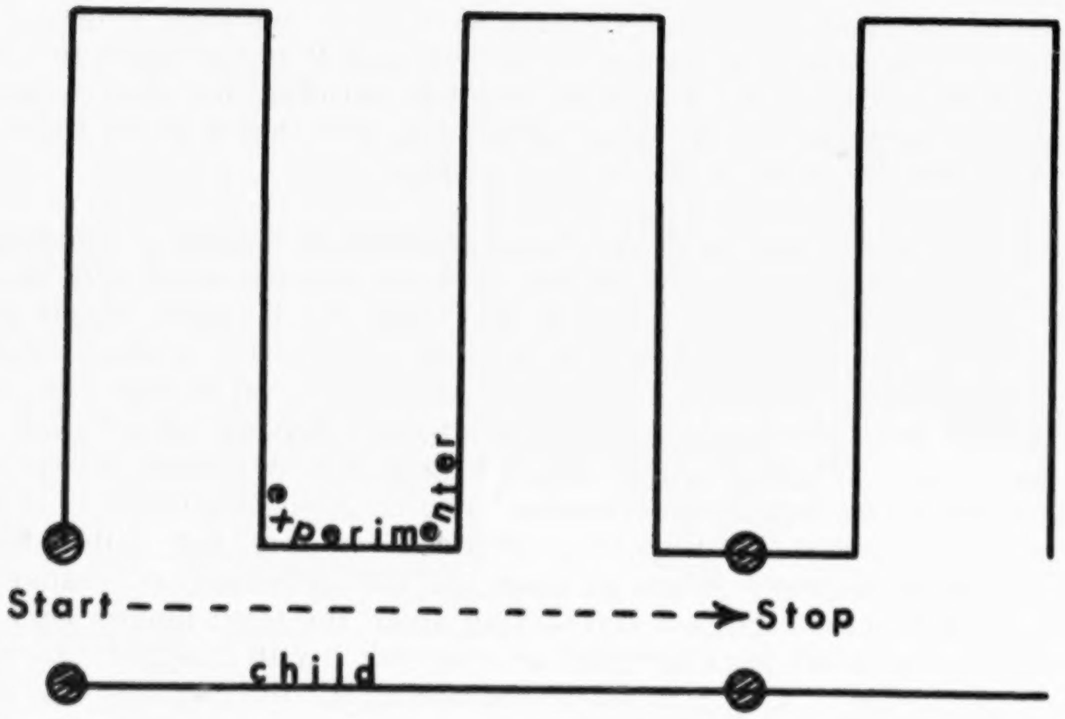

Figure 3

Then we would put our beads back at the beginning and I would start over again and put my bead here. (Figure 4) The child would put his bead underneath it, saying, "There, I've done a trip just as long, I'm there underneath yours." Then I would say, "But I did all that, and you only did that much. Does that look right?" And he would say, "Of course it's right, since my bead is here."

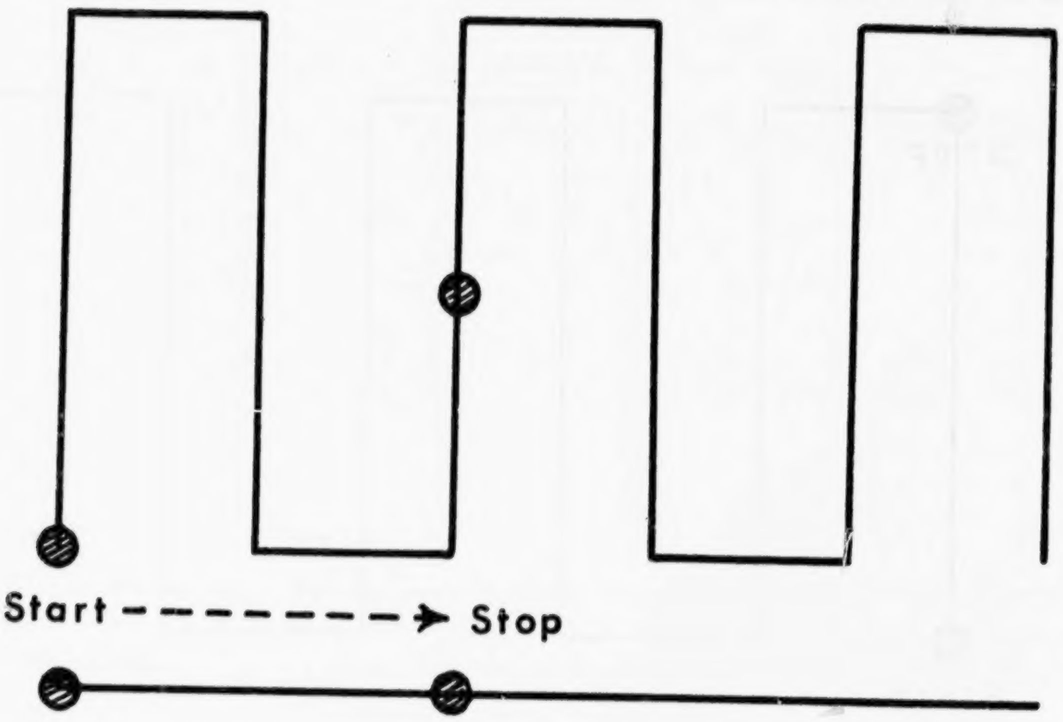

Figure 4

Finally I started over again and put my bead there, (Figure 5) so the child didn't know what to do. He would say, "But I'm there." So I would say, "But I did that whole trip and you haven't moved at all. Did you do a trip just as long?" Then he would say, "Oh, that's right, I've got to go a bit further." So he would move his bead a little bit, but he would stop there and say, "No, I've gone too far," and he would come back to the starting point. Well, here is a first reply which seems to indicate that there is not only a linguistic confusion, since the child is troubled and oscillates between the ordinal evaluation and the integral evaluation. This still is not sufficient proof that he has understood that we are referring to the integral evaluation, however. So we went on recently to see what we could tell from the child's imagery in his predicting this displacement. The child is given the two sticks as before, but after they are laid on the table side by side, we cover one end of them. Then in pushing one of them, we can ask the child where the hidden end of it will be and we can see whether according to his imagery the difference at one end is the same as the difference at the other. With this experiment, the anticipations by means of imagery were absolutely conclusive. Before reaching the level of conservation, the child is incapable of predicting that the difference at one end will be the same as the difference at the other. He always estimates that the difference at the end toward which the stick has been pushed is greater than the distance at the other end. In other words, this study of anticipatory imagery enables us to confirm our interpretation that we have here a real situation of non-conservation, that is, an inferential or deductive insufficiency, and not simply a semantic confusion. Once again, you can see that imagery is not sufficient and anticipation is not possible as long as there is no operational transformation upon which the imagery can be based.

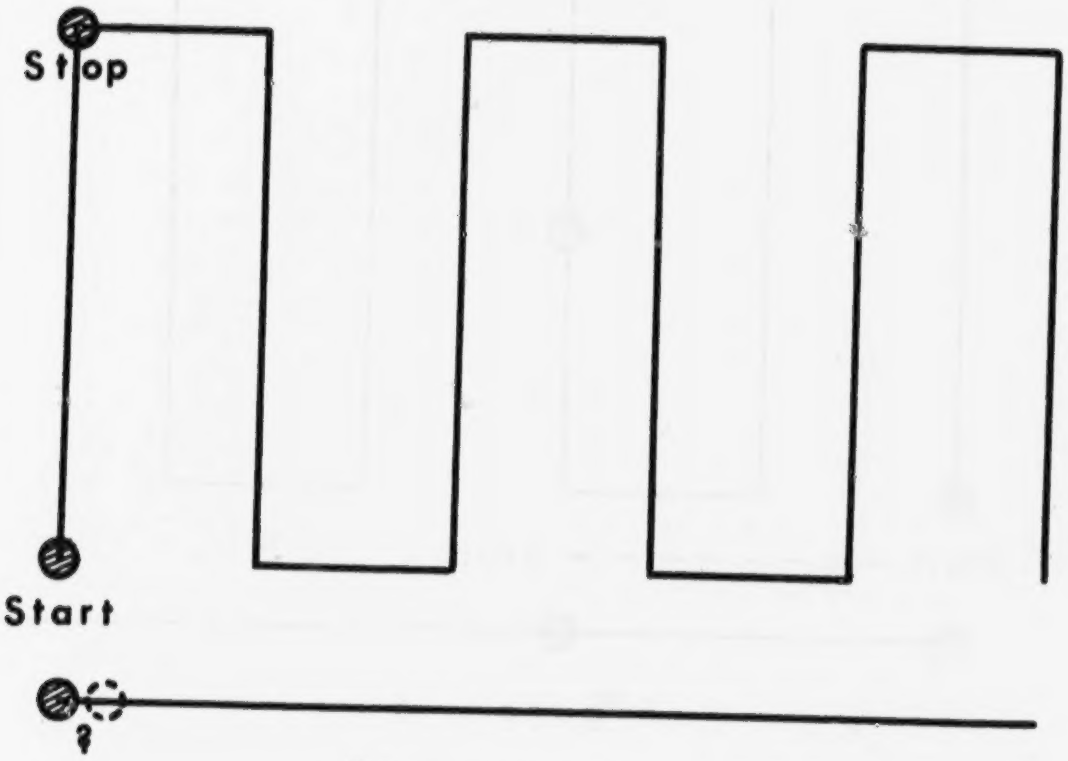

Figure 5

By way of conclusion I would like to bring up briefly two problems. The first is this: The facts which I have related are, of course, much too meager and schematic to conclude anything, but they are only a few examples drawn from a great number of others which I don't have the time to relate. A question which is raised is, "Do these facts seem to indicate that operations are prepared for by imagery -- by the figurative aspect of representational thought?" By way of answer it seems that on each of the points that we discussed, we have seen that the initial imagery is inadequate and that it becomes adequate only when the operation becomes possible. Or, on the other hand, the image is adequate (That was the case for a fraction of children in the example of the pouring of liquids.) but even in these cases this adequate imagery does not suffice to engender operational conservation. Consequently, I conclude that operations involve more than just imagery. An operation has to do with a transformation -- a transformation which is part of a whole system, a whole structure, where there is a transformation in one direction and the possibility of reversibility in the other direction and the coordination of several operations, etc. These images, though adequate, do not present these characteristics. They are simply copies, more or less faithful, of what has already been seen.

The second problem is that of the evolution of imagery. We have seen that the imagery of small children is not identical with the imagery of bigger children.

The images of small children are, above all, what we can call reproductive images. They reproduce representations of situations that have been perceived already. Anticipatory images -- images which imagine the result of a transformation as yet unknown, but which could be predicted on the basis of some reasoning -- are not yet possible. In the one case where there seems to be a correct anticipatory image, e.g., in the case of the pouring of liquids for some of the small children, what we had really was a reproducing of experience already seen. In other words, this is just a reproductive image. At an average of about seven years, but sometimes much later, imagery can become anticipatory. The problem is to know how this evolution takes place. Is it an internal, independent, autonomous evolution like the evolution of operations in the field of intelligence, or on the other hand, is it an evolution which is determined by support and enrichment from some other source external to the imagery itself? The facts which I have presented to you, although they are too meager to base conclusions on alone, seem to indicate that the evolution of imagery is not autonomous but evolves only through the direction of intelligence. Imagery is a kind of interiorized imitation which, like all imitation, supposes a certain amount of understanding and is thus directed by intelligence. So while intelligence still does not have a basis of operational structures, the imagery remains meager, remains static, remains reproductive. It does attain the mobility of anticipatory imagery, but at the level where operations become possible and enable the child to think of transformations from one state to another, we find an action of the operations upon imagery. The imagery itself becomes more mobile, becomes anticipatory. Now it becomes an instrument of representation capable of serving the operations. It is a symbolic instrument and an auxiliary instrument which is not an element of thought itself, but is simply a tool, an aid to the process of thought -- an aid that takes the form of figurative representation. These representations become much more helpful when they are supported by operations and so can deal with transformations themselves, not only fixed states.

Editor's note: At the conclusion of Professor Piaget's presentation one of the conferees noted that the age of seven seemed to be a critical one in terms of intellectual development. He asked if this was a more important psychological age than was believed in the past. Professor Piaget's response follows:

The age of seven is a relative one in a double sense. In our research we say that a problem is solved by children of a certain age when three-quarters of the children of this age respond correctly. As a result, to say that a question is solved at seven years old means that already one-half of the six-year olds can solve it, and a third of the five-year olds, etc. So, it's essentially relative to a statistical convention. Secondly, it's relative to the society in which one is working. We did our work in Geneva and the ages that I quote are the ages we found there. I know that in certain societies, for instance in Martinique, where our experiments have been done by Monique Laurendeau and Father Pinard, we have found a systematic delay of three or four years. Consequently, the age at which those problems are solved is also relative to the society in question. What is important about these stages is the order of succession. The mean chronological age is variable.

MOTHER STRUCTURES AND THE NOTION OF NUMBER

Jean Piaget

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In his third presentation Piaget shows how studying the development of knowledge in children resolves problems inherent in understanding human knowledge in general and scientific knowledge in particular. Mother structures in mathematics (as arrived at by the Bourbaki group) and the notion of number are used as examples. Piaget maintains that the mother structures of the Bourbaki group correspond to the natural, spontaneous development of children's thinking. Examining the development of the concept of number in children suggests to Piaget an alternative to intuition and logical structure as the basis of the formation of number.

My dear colleagues and friends, I am not going to talk about pedagogy this morning. I have been asked to talk of very general questions, and even to dream out loud. So I would like to say a few words about why I took an interest in child psychology and why, from my point of view, child psychology throws some light on human knowledge in general and in particular on the nature of scientific knowledge.

The sciences are in constant evolution and are changing every day. Mathematics has been profoundly transformed in a few dozen years. Physics changes every day. Biology changes every day. Logic, which was for a long time considered to be definitively established by Aristotle, has been profoundly transformed within the last century and is still changing every day, etc. As a result, to understand the nature of science and of scientific knowledge, it is imperative to look at their history, that is, to try to understand how scientific notions are transformed, and above all, how they are formed. The history of science gives us a part of the answer about how they are formed, but the history of science is insufficient in that most of the fundamental notions of scientific knowledge, like number, elementary logical structures, the notion of cause of law, etc., are notions that came from common sense before the formation of sciences themselves. Consequently to understand how human knowledge has been formed, we would have to follow the history of this human knowledge back to the origins of man. Unfortunately, we know nothing at all about prehistoric man. We have some material traces and some ideas of his techniques, but we have not the slightest information about his thinking or the structures of his knowledge. As a result, we must do as we do in biology -- go back to embryogenesis.

Now, in the field of knowledge, there is an embryogenesis of knowledge in children. Of course, children are always influenced by the social environment, so you could say that the child is in part a product of human history. But, on the other hand, the child comes before the adult. No matter how far back you go the child always came before the man. The child is more ancient than prehistoric man since prehistoric man began by being a child. So, we have some possibility, through studying the development of knowledge in children, of resolving certain problems which cannot be solved simply by looking at the history of science, the history of adult ideas. And in this talk, I should like to give three examples. One example is that of the mother-structures of the Bourbaki group. The second example is that of the notion of number and the third is that of relations between time and speed as physical notions.

I shall begin with the problem of structures as considered by the mathematicians of the Bourbaki School. The Bourbaki wanted to find the fundamental structures which are in common among all the different branches of mathematics. In other words, they wanted to get away from the classical cloistering of the different branches of mathematics and look for what there is in common from the structures of one branch to the structures of another. Proceeding by structural analysis based on isomorphisms, the Bourbaki came to the conclusion that there are three fundamental structures and that all the others can be drawn from these three either by combining the three or by differentiating and specializing one of the three. These three structures are fundamental because no one of them can be reduced to either of the others. They are irreducible and consequently considered to be fundamental.

Now, the problem which I raise with you is this: Are these structures simply an artificial product of a theoretical and axiomatic analysis, or are they natural? That is, do they correspond to something in human intelligence and in particular in the intelligence of children?

Algebraic structures are one of the three kinds distinguished by the Bourbaki. The algebraic structures are based on operations whose prototype is the group. The fundamental characteristic of these algebraic structures is the possibility of combining a direct operation with an inverse operation, and thus to negate it. In other words, the form of reversibility characteristic of algebraic structures is what I call reversibility by inversion or negation. It negates and thus gives a null product when the direct operation and the inverse operation are performed jointly.

The second type of basic mother structure includes all the ordering structures. The ordering structures are based on relations. The prototype is the lattice structure. The form of reversibility which characterizes lattices is not inversion in the sense of negation as is the case with algebraic structures, but it is rather what we can call in psychological language reversibility by reciprocity. Let us take as an example the duality law of lattices. Let us start with the statement, "The lower limit precedes the upper limit." Now if you apply the law of duality, you replace "precedes" by "succeeds," and you permute the positions of lower limit and upper limit so you come to the statement, "The upper limit succeeds the lower limit." As you can see, this is not a negation, it is simply a reversal -- a reciprocity, we shall say, instead of a reversibility by inversion.

Finally, the third mother structure is the set of topological structures based on the concepts of proximity, continuity, continuous correspondence, limits, etc.

Now, I maintain that these three structures correspond to something in natural intelligence and specifically in the thought of the child. If we attempt to formalize the operations used by a child at the concrete operational level, that is, the first and simplest operations used by the child, we shall find that these structures are much simpler than the mathematicians structures. They are not formalized but simply applied in practical operational intelligence. In formalizing these operations, however, we find the same three structures described by the Bourbaki mathematicians. First of all we can find what I shall call "groupings" -- that is, imperfect groups. Classification is an example of a grouping. (See Figure 6) Class A is enclosed in class B with the complementary class A-prime. Class B is enclosed in class C with complementary class B-prime. C is enclosed in D with complementary C-prime. The operation here is the union of classes. The form of reversibility which applies to these operations is negation, an inversion which amounts to annulling the original operations. So, we find here in the simplest, most elementary form, an algebraic structure.

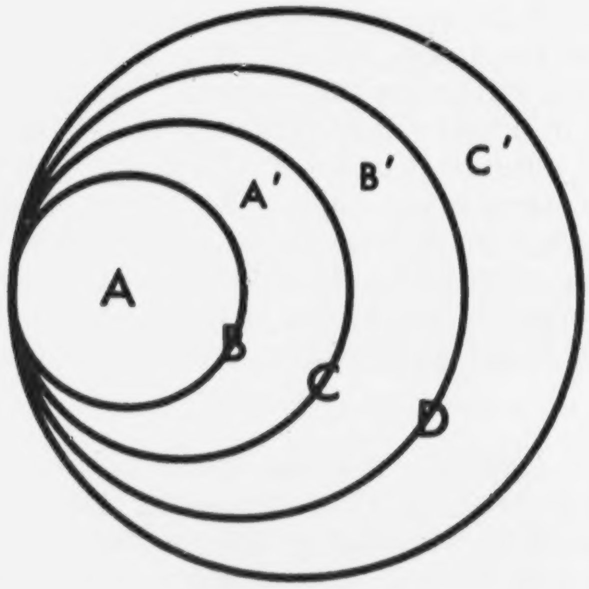

Figure 6

Secondly, right from the beginnings of concrete operations, we find ordering structures. In its most general form, a series can be written in this way: X precedes Y, Y precedes Z, etc. The form of reversibility which applies to these theories is not negation, but simply the reversal of the relations. It is reciprocity resembling what we saw in the case of lattices.

Thirdly, there are topological structures. The spontaneous development of geometry in children shows some remarkable relationships to the development of the history of geometry. In the case of the history of geometry, as you well know, the Greek geometers began with what is called today Euclidian geometry. The Greeks touched upon projective geometry but did not develop it. This was not developed, in fact, until the 17th century. It was not until the 19th century that topology was discovered as a branch of geometry and seen moreover as the most general branch of geometry. So the historical sequence goes: Euclidian, Projective, Topological. Now, Felix Klein undertook a theoretical study of the sets of axioms on which each specific geometry is based. He found that each geometry is based on a fundamental group of axioms and that there were several such fundamental groups for which he could find a still more fundamental general group of axioms until he arrived at one set of axioms from which all the others could be derived. In this formulation we can see that topology is the basis, is the most fundamental type of geometry. Starting from topology, you can proceed on the one hand to projective geometry or on the other hand to metric geometry in general with Euclidian geometry as one specific case.

Now, if you look at the development of the geometric operations in children, you find that the most elementary ones are topological. There are topological intuitions before the metrical intuitions. For instance, if you give a child of about three and one-half years old figures of the kind in Figure 7 to copy, he will copy them all as closed curves without paying attention to the metric characteristics, the equality of the sides, angles, etc. If you give him the type of drawing in Figure 8 to copy, he will copy them simply as open curves. If you give him a series like the one in Figure 9 with one constant figure and another one either inside this figure or outside it or on the border, he will have no trouble copying this even though he cannot yet copy a square or make a closed triangle which differs from a circle. In other words, the topological structures have their beginnings before the projective structures and before the metric structures. The child's first geometric operations will be built on the basis of these topological structures and these operations are those of separation, of ordering, of localization, etc.

In other words, I maintain that the three mother structures of the Bourbaki group correspond to something in the natural thought of the child. In a colloquium dealing with mathematical structures and mental structures, Dieudonné, representing the Bourbaki school, was talking about their mother structures and I, who at that point did not know their work, was talking of psychological structures. We were both astonished by the resemblance between these two types of structure. Dieudonné exclaimed at the end of my remarks, "This is the first time in my life that I have taken psychology seriously!"

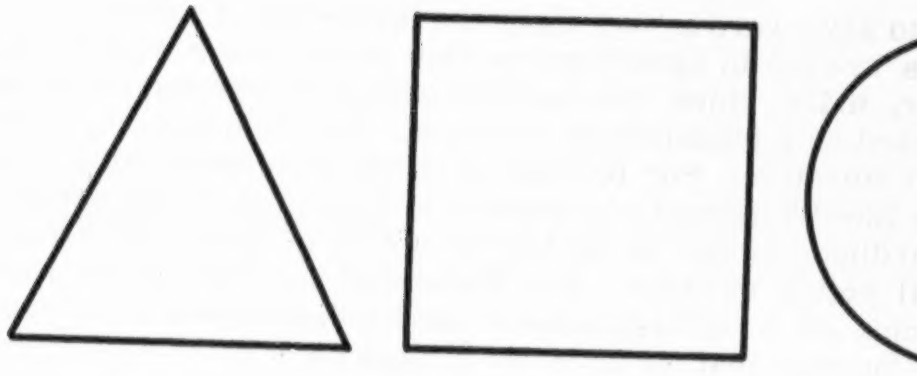

Figure 7

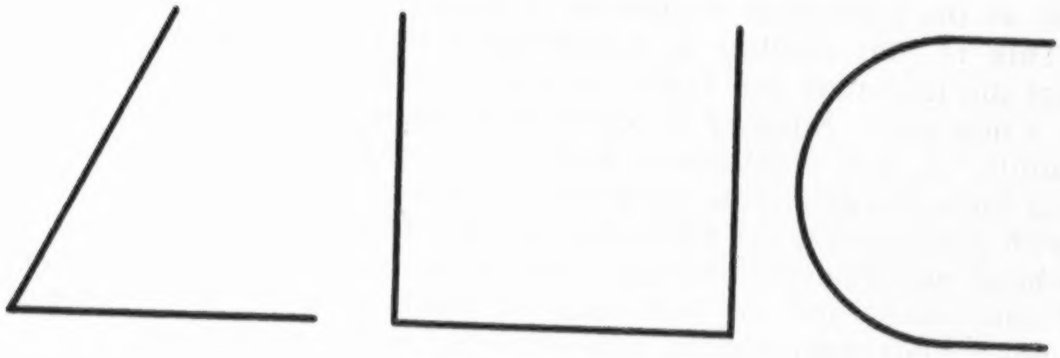

Figure 8

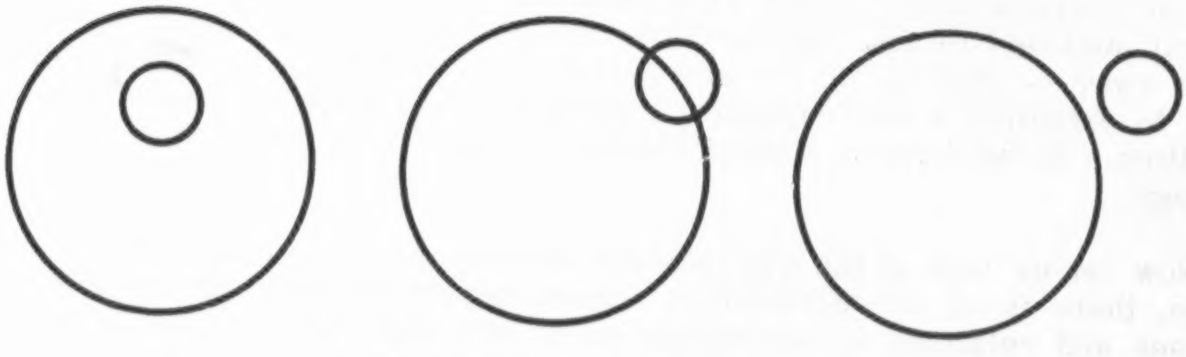

Figure 9

Now I should like to say a word or two about the formation of number. As you know, mathematicians are not in agreement on this point. Some, like Poincaré, formerly, and Brauer, today, think that number cannot be derived from logical structures, but is based on a fundamental intuition. For Poincaré, this was the intuition of N + 1, of iteration. For Brauer, it is the intuition of unity. On the other hand, logicians like Whitehead and Russell in Principia Mathematica have tried to reduce the cardinal number to the logical notion of class and the ordinal number to the logical notion of order. For Whitehead and Russell the cardinal number is based simply on a correspondence established between classes with the same extension. Suppose that we have two groups each containing three objects. Then we can establish a correspondence between the elements in one group and the elements in the other group. The number three is the class of classes which are equivalent. The number then would be wholly reducible to classes in the case of cardinal numbers and ordering in the case of ordinal numbers.

If we look at the formation of number in children, a third type of solution is suggested. This is that number is indeed based totally on logical elements and in this respect the logicians are right. However, it is based on logical elements combined in a new way. Number is based on a new synthesis and this synthesis is not reducible to the elementary logical structures. In point of fact, when Whitehead and Russell reduce the cardinal number to the notion of class, we are confronted with a psychological difficulty, which I believe is also a logical difficulty. Whitehead and Russell call upon one-to-one correspondence between the elements of one class and the elements of another class. But, there are two types of one-to-one correspondence. One of these I call qualified correspondence. In this case an element is made to correspond with another element which has similar qualities. For instance, a child will put a square under a square, a circle under a circle, a triangle under a triangle, etc.

The second is a non-qualitative type of correspondence where any element can correspond to any other element independent of their qualities. It is this type of correspondence which calls upon a unity. These elements are no longer logical qualified terms, but they are unities by virtue of having their qualities taken away -- that is, we are now dealing with numbers. Number is necessary here to establish a correspondence since it is a correspondence independent of qualities. So we have a vicious circle, at least from the point of view of psychology.

Now let us look at the way children develop the idea of number. In the first place, there is no conservation of number before the development of notions of classes and relations so we cannot speak of a cognitive intuition of number as Poincaré and Brauer do. Number is based on a system of inclusions: one is included in two, two is included in three, etc., and this is similar to the class groupings which we were speaking of a moment ago -- simple classification. But number ignores qualities, so there is more than simple classification. A is included in 2A, which is included in 3A, etc. But, if you are dealing only with classes, we have a tautologous situation: A + A = A, and not 2A, while in arithmetic one + one = two, and not one. We must, then, try to understand how to go from the tautology involved with classes to the iteration involved with number.

What the child does is very simple, very elementary. The second A is not identical with the first simply because it comes after -- because there is now an element of order. It comes after the first one, the third comes after the second, etc. In other words, number cannot be reduced to class alone, but is a synthesis of class inclusion plus ordering. In number you have both inclusion and ordering which makes it possible to distinguish among the terms. Without this element of ordering all the terms would be indistinguishable and the situation would be tautologous. This, then, is the solution which we reach when we look at the child's construction of number. Number is a synthesis of class inclusion and serial ordering, but it is an indisociable synthesis. We cannot speak of a cardinal number on one hand and an ordinal number on the other. We always have both at once...that is, in dealing with finite numbers, of course. In transfinite numbers it is another question, a question of different structures.

If you read Whitehead and Russell carefully, you find a small passage which is almost hidden and which is aimed at avoiding this difficulty in going from tautology to iteration. In this small passage Russell and Whitehead write that A + O is not the same thing as O + A. In other words, they do distinguish A by order so there is an element of order which comes surreptitiously into the demonstration. This is very interesting and seems to justify what we have just said based on children's thinking. In other words, here the child furnishes us with a third solution which seems to me to clarify the debate. It's a solution which I have given you here only intuitively, but it can be given a logical formulation and my collaborator, the logician Grize, has proposed such a formalization in our published studies of genetic epistemology.

RELATIONS BETWEEN THE NOTIONS OF TIME AND SPEED IN CHILDREN

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Opening his final remarks with an observation on the role of research in the training of teachers, Piaget goes on to discuss research on the relations between the notions of time and speed in children. Three stages in the development of the concept of speed are identified--ordinal, hyperordinal, and metric. Notions of time are held to be dependent on notions of speed. On the basis of his research Piaget concludes that time is a coordination of speeds and space is a coordination of displacements.

Today, I want to talk above all about research we have been doing on relations between the notions of time and speed in children. We have been working on this problem a long time, and still are working on it because it is a very difficult one. This leads me to detour for a moment, and to make one remark of a pedagogical nature on the training of teachers. It is my belief that teachers should not only learn psychology, child psychology in their courses, but to do research, to actually carry out their own research to see how difficult it is to make themselves understood by the children and to understand what the children are saying. The illusions that teachers have in front of classes of children are that they are making themselves understood and that they are understanding. These are two illusions that must be dissipated. If they are going to be at the level of psychological understanding which they need to be good teachers, they must not only read about research but practice it. Reading about, and practicing research, are two quite different things. The teachers should be active in research instead of reading about research passively, which always results in some sort of deformation.

I go on now to discuss notions of time and speed. In classical mechanics speed is seen as a relationship between space and time. Space and time are the simple intuitions and speed is a relationship between them. In the theory of relativity, however, speed is an absolute with a maximum. The maximum speed is the speed of light and time and space are relative to speed. On the other hand, in physics, there is a vicious circle. Time is measured by speed, the speed of a pendulum swinging or the speed of celestial motion. And speed is defined by time, so that each one of these depends on the other one. This poses a problem from the view of psychology. A number of years ago I was at a symposium on philosophy of science which was chaired by Albert Einstein, and he was very interested in our experiments on the thinking of children. He suggested to us to look into the relationship between time and speed in children's thinking to see whether one of them depended on the other, whether one was more primitive, or how they had been related. We have been working on this problem for a long time and we are still working on it because there are always new aspects which come up in this difficult problem.

Let us start with the concept of speed. There is a metric notion, corresponding to mechanical physics, but it appears quite late. Not until the age of nine or ten does it start to appear, and it stabilizes with the beginnings of formal operations at age eleven or twelve. But before this there is a primitive intuition of speed which is ordinal and not metric. That is, it does not depend on a relationship between the time interval and the spatial interval but only on relating the order of events in time with the order of events in space. Time has in fact two aspects: the aspect of the ordering of events, and the aspect of a duration of a time interval. The primitive intuition of speed depends upon the notion of order but is independent of the notion of interval, of the length of time. The primitive intuition of speed is that of passing. Suppose you have two things in motion, A and B. At the first point in time B is behind A. At the second point in time B is ahead of A. In a case like this children will acknowledge that B has gone faster. There is an interversion of spatial order and temporal order. That is, in going from one spot in time to another spot in time, the spatial order is inverted. So this primitive intuition depending on order precedes the metric intuition and is present already at the pre-operational level. There remain some difficulties at the pre-operational level -- for instance, in the case where two moving things started at different points, the front one going more slowly and the second one catching up with it. If you stop the experiment before the second one has caught up, the pre-operational child would say that the front one was nonetheless going faster because it had gotten farther along; he cannot anticipate the passing that would take place later. At the operational level he will be able to evaluate this passing even in anticipation and will realize that the one that has gone farther in the same time has gone faster.

There are three stages in the development of the idea of speed. The first one is ordinal; we were just talking about that. There is a second brief period around nine or ten years where there is not just the order of events but also some consideration of the size of the intervals. If one mobile is behind and catching up, at first there is a big interval between them, getting smaller and smaller until there is no interval, and then getting bigger and bigger. It is not yet a question of taking into account all of the space covered from the beginning, but there is an ordinal relationship of intervals. This is what we call hyperordinal, using Suppes' terminology.

In the third stage there is a relationship between space covered since the beginning, and the time passed since the beginning. This is the metric notion of space, speed being the relationship between space and time.

In considering the first stage I would like to tell you about one more experiment which confirms the fact that at this stage time and distance covered play no role. This experiment involves two tunnels, a long one and a short one, lined up evenly at one end. We ask the children whether they are the same length and none of the children has any difficulty in admitting that one of them is longer than the other. We have little men that we hold at the end of each tunnel (one man at the end of each tunnel) and have them go through the tunnels until they come out the other end. We have it regulated such that they come out the other end at the same time. Then we ask whether they went at the same speed or whether one went faster. The little children say that they went at the same speed since they got there together. Then we ask, "Isn't one road longer than the other?" They will say that it is. "Well then did they go at the same speed?" and they say, "Yes, they came out together."

Next we take the tunnels away and all the children say that one went faster because they see the passing. Finally we put the tunnels back, and at that time children of about six years old will say, "That one went faster because I saw it underneath." But the little children will go back to their same answers -- that they went at the same speed because they got there at the same time. When the passing is not visible, there can no longer be an evaluation of the speeds.

I should like to bring in a few experiments dealing with the perception of speed -- not the concept of speed, but the perception of speed -- in both children and adults. There has been a lot of research in this field already, notably by Brown, among others. Brown believed that the perception of speed came down to the relationship of space over time but that it was a question of phenomenological speed, based on phenomenological space and phenomenological time. That is, subjective evaluations of speed were based on subjective evaluations of space and time. I re-did some of his experiments and added a great many more and found that all perception of speed can be explained by ordinal and hyperordinal relationships. Metric relationships never came into the perception.

Now we can do experiments in two ways--either by having two mobiles or by having a single mobile with the motion of the eye itself as the other moving element. First of all, if we have two mobiles we have the same situation as in the pre-operational concept of speed. That is, there are only ordinal or hyperordinal comparisons. For example, if you have two mobiles, where one catches up with and passes the other one, at the point where it passes there is an effect of apparent acceleration of one or else deceleration of the one being passed. This perceptual illusion is exactly what happens for children at an ordinal level of understanding the notion of speed.

If we have a single mobile, we perceive speed anyway. We can perfectly well say whether it is going fast or slow. You may ask how this can be the case. Well, there may be two situations: one where the subject looking at it is free, where his eye motion is free; and the other one where it is immobilized. This second case would take too long for me to talk about now, but I'll mention a couple of experiments in which the subject's eye motion is free. In this case the eye motion itself is one of the mobiles, so there are once again two mobiles.

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Now we encountered a number of effects which had already been encountered by Brown and others and we found that they can be explained by ordinal and hyperordinal comparisons rather than by metric. First, there is the effect of the initial appearance of a mobile. At the moment that it comes into the field, it appears to be going faster, and then it seems to slow down and maintain a constant speed. This can be explained by the fact that at first the eye is motionless and it takes a while to get going with the mobile. It has to catch up. While it's still trying to catch up, the mobile is ahead of it and so the mobile seems to be going faster. When the eye movement catches up, then the mobile seems to go at a constant speed. But first of all, at the moment of appearance the mobile seems to be going faster than later. You can say that this interpretation by ordinal and hyperordinal comparisons is just speculation, and that it has to be proved. By way of proof I can point to the effect of retinal perseveration. Yet the mobile is not at first clearly perceivable. It seems to have a tail, or a wake as behind a boat, and this is because the eye motion has not yet caught up with it. Later the mobile is perceived clearly because the eye is moving steadily with it.

In the second experiment, half the field was split up by vertical lines, and the other half was open. In the first half, if a mobile goes at a constant speed, it seems to be going faster because the eye is fixed at each bar so once again there is a little bit of delay; the mobile always seems to be ahead of the eye so the mobile seems to be going faster. This is very interesting because here we can verify Brown's hypothesis that perception of speed is the result of an evaluation of subjective space and subjective time. But here we can and did ask adult subjects to compare the sizes of these two halves of the field -- to compare the times the mobile took to move through each half, and to compare the speeds at which the mobile was moving. Then we could see whether these impressions were coherent. We found that with adult subjects who were psychology students, who are not less intelligent than any other sort of adults, there was a 60% incoherence with respect to the formula of speed equalling space over time. So speed does not seem to be perceived metrically but by ordinal and hyperordinal relationships.

We have seen that speed is independent of time duration, both in perception and in the elementary notions. I will go on now to the notion of time in children. We can look at time in two ways: by order of succession of events, including simultaneities, or by time intervals. We find in both cases that notions of time are dependent on notions of speed.

We begin by simultaneity. In this experiment we have two men walking along. The child gives the signal to begin and the signal to end. We make a sound on the table at each step along the way, making the two go together. If we do this at the same point of departure and the same point of arrival there is no difficulty. The children will admit that they have started at the same time and they have stopped at the same time. But then if we make one of them go faster, at bigger jumps, so that by the time the child says, "Stop," he is at a different point, the child will refuse to admit that they stopped at the same time. You could say that this is a perceptual problem. But it isn't, because then you can ask, "When this one stopped was that one still walking?" "No." "When this one stopped was that one still walking?" "No." "So then did they stop at the same time?" "No, they didn't." So that you can say there is no evaluation of simultaneity, of "same time," except within one movement. There is an evaluation of order within one movement, but it is an ordering of events internal to a single event and doesn't seem able to be coordinated among events at this early age.

At about six years old children will accept the simultaneity of points of arrival but still the duration of the time interval proves to be a difficulty until about eight or nine years. They will say the two stopped at the same time, but still this one walked a longer time, because it went farther. Often they will say it walked a longer time because it went faster and this time faster is equal to more time. In spite of language, speed is not being presented as a relationship between time and space, because in fact more speed means less time, not more time. But at this pre-operational understanding, more speed, faster speed, is taken to mean going farther or doing more work and therefore more time. Finally, at the operational level time is understood as a relationship between speed and space. Very little children take into account only one of these things at a time and not both at once. Later, speed and space are coordinated, to give a correct notion of time.

I would also like to say a few things about perception of time. Once again we find a correspondence between perception of time, in both children and adults, and the pre-operational notion of time. We present the mobiles on film, both in these experiments and in the experiments on speed perception. It is much easier to regulate the movement. In the first experiment we present two mobiles which start and stop at the same time but go at different speeds. The illusion is that the one that has gone faster disappears first. There is a consistent perceptual illusion that the point of arrival is not simultaneous.

The next experiments deal not with the order of events but with the duration of events in relation to their speeds. In the first experiment we present two film sequences successively. In one of them there is a fast movement of the mobile and in the other a slow movement of the mobile. But in each case the time is the same. After they have seen both sequences we ask subjects to compare the time passed in the two cases. Adults and children both estimate that the faster one took longer, the slower one took less time. In another experiment we present these two mobiles not successively but at the same time on the same piece of film -- but we ask the subjects to focus on one of the mobiles at a time. We indicate which one he is to focus on by a little red dot. In this case, the faster movement seems to disappear first -- that is, to last less time and the slower movement seems to last a longer time. In other words, in the first experiment with successive motion, the subject judged on the basis of the results, on the basis of the amount of space covered, while when both movements are presented at once and the subject is required to fix on one or the other, he must of necessity take speed into account. In this case then, he corrects his subjective impression of time, but he over-corrects.

Now I should like to talk about speed -- not of spatial displacement but of frequencies, that is, the number of events per time unit. One of my colleagues, Fresse, has done a lot of work in this area and we have done a lot of discussing and comparing of results. One of his experiments was to present a certain number of pictures during a fixed time interval, and to ask subjects to evaluate the time. There are two conditions, 16 per minute or 32 per minute. His adult subjects are asked to evaluate in minutes and seconds how long they have been watching these go by. First they watch the 16 and estimate length of time. Then they watch the 32 and make another estimate. He found to his surprise that there was no illusion in adults. For children there was a problem of getting at their estimation because we couldn't ask them to estimate in minutes and seconds. One of my colleagues drew on an experience he had had a few days earlier with his daughter, who said, "I love Mommy this much and Daddy this much." So we took sticks, six sticks of different lengths, as approximations of different amounts of time and had the child tell us about how much time passed by indicating one of the sticks. The results were very clear. First of all up to about eight years of age the children said it was a longer time where there were 32 images in a minute. In this case time was again evaluated by how much was done during the interval. From eight to eleven, they said it was a shorter time when there were more images, because things were going faster. After eleven some of them came to say they take the same time. "There were more but they went by faster," or else, "There were fewer but they went by slower," so the speed and frequency compensate for one another. From these experiments and others I have come to the conclusion that time is a coordination of speed, just as space is a coordination of displacements, that is, of movements without speed.

One further experiment, similar to the one of the two men going along the table, should be mentioned. In this experiment water runs out of two taps into two glasses. The glasses are the same shape, and the children will admit to the simultaneity of the start and the end of the flow. But if you change the shape of one of the glasses so that the water gets to a higher level, although the water starts flowing at the same time and stops flowing at the same time, the child will once again deny that it stopped flowing into the glasses at the same time. They will maintain that it was flowing into the glass with the higher level longer, just as they maintain that one man keeps walking for a longer time. In all of these experiments, the man walking and the water flowing and the others, you might say it would help to put a time measuring device in front of the child -- a stop watch or a sand clock or something. Of course we have done this, and we find that it helps not in the slightest. There is this remarkable result. If one event has seemed fast, the child will say that the clock went slower. If the event seemed slow, he will say the clock went faster. At a pre-operational level, there can be no time measure, no notion of measuring time, because there is no conservation of speed. So my hypothesis is that time depends on coordination of speed.

Now I want to go on to the operational understanding of time to see in what way a metric notion of time is coordination of speed. So far we have only been dealing with the primitive intuition of time. In one of our experiments we have an apparatus of pear-shaped glass with a tap controlling the flow of water into a round glass underneath. We can let the water flow a bit then seal it off. The child does this for a while. Then we have a number of sheets of paper where the apparatus is drawn but there is no water level indicated. The child is given eight or nine sheets of paper and he draws the water levels in the two glasses as he sees them at successive moments in time. In this experiment we can study the child's ideas about order of succession. Since the level in the top glass gets lower and lower, we can study his ideas about time intervals. Thirdly, we can study here the possibility of introducing measurement.

First of all we will look at temporal order. After he has done his drawings we mix them all up and ask him to put them in order. Where was the water at the beginning? How was the water at the end? How did it go from the beginning to the end? After he has done this we use scissors, and I remember one little boy who said at this point, "I know just what you are going to do. You are going to cut them all in the middle and make me do it over again." That is precisely what we do. (See Figure 10) We cut them all in the middle, and mix them up. Then we take out one half drawing and ask, "When the water was here in the top where was it in the bottom?" The child has to make an ordered correspondence between the two series to find the one at the bottom. Well, this problem is solved correctly at about seven years of age, like all other problems of ordering.

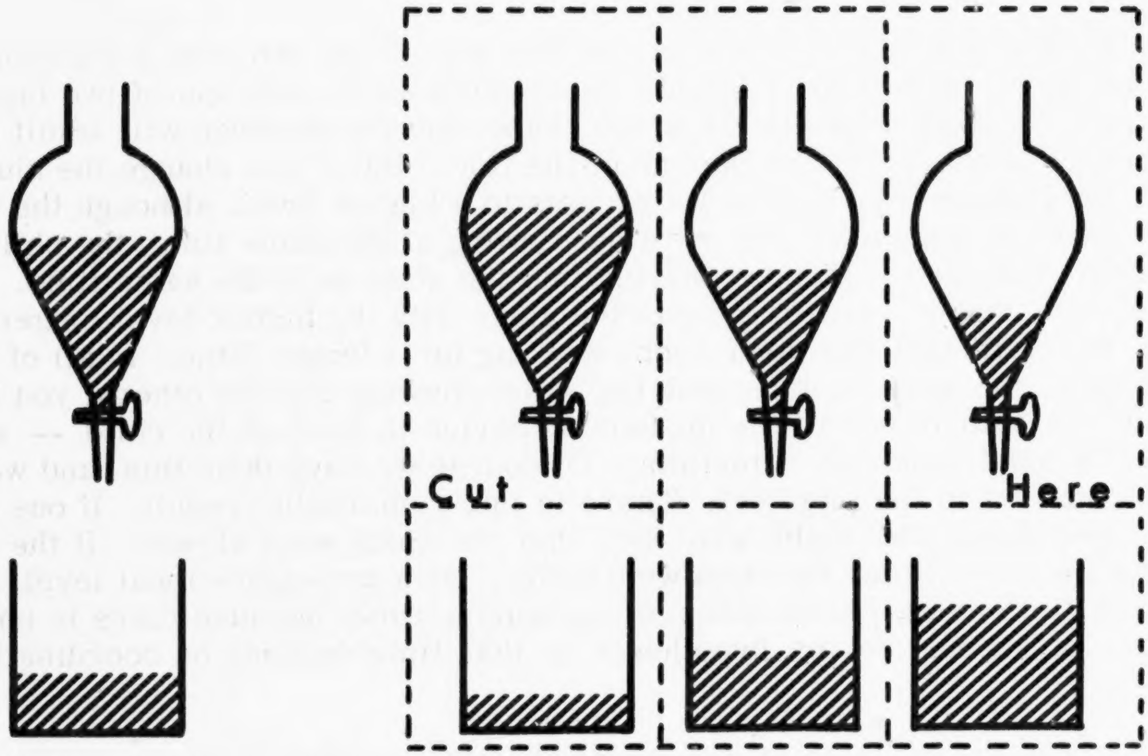

Figure 10

The second part of the experiment deals with the notion of inclusion of time intervals within one another, and conservation of the total time interval as the sum of the smaller time intervals. We mark successive levels on the outside of the glasses. We mark where the water was at the time of departure, then we run a little water out, mark where it is in both beakers, let it run again and mark where it is in both beakers, etc. You can see that there are different spatial intervals in the two glasses, because of their different shapes. (See Figure 11) Then we ask questions about more or less time -- whether it took the same amount of time to go from here to there as it did to go from here to here, etc., or whether it took the same amount of time to go from there to there as it did from there to there -- all sorts of questions of this type.

The very interesting result, and very instructive from the point of view of philosophy of science, is that little children say, "I don't know. The water's gone, I can't tell." They feel that they can't reconstruct the time in the past or anticipate it in the future; they can only deal with time in the present. This shows that although physical time is in fact irreversible, the operations necessary for dealing with time are reversible. To reason on time you must be able to reconstruct it -- to reconstruct the time that's past and to conceive of time in the future. Without reversibility you simply cannot reconstruct the flow of time and can't reason on time at all. But once again at about eight years old we find the inclusion of time intervals in both directions -- reconstruction of the past as well as anticipation of the future.

Finally, we come to time measurement -- metric time. When you have the inclusion of intervals and ordering, you have a basis for a unit with which you can construct a measurement system in the same way that you can construct a spatial measurement system. There is temporal meter, of course, which comes spontaneously in natural thought. You mustn't think that temporal meter was invented by astronomers or by science. In natural pre-scientific thought, in children in the context we are discussing, or in cultures in general, there are all sorts of spontaneous temporal meters. In music there are half notes, quarter notes, and eighth notes, which are temporal unities related by simple proportions, simple numeric relationships and which constitute a spontaneous meter, as in folk songs for instance. There is classical poetry -- poetry of the Greeks and Romans -- which is based on long syllables and short syllables. Syllable length both in poetic language and in everyday language assumes an elementary temporal meter.

So we see that these three operations -- ordering, inclusion of intervals, and metric relationships by a synthesis of these two others -- give you the temporal operations. But there is a fundamental condition which seems to me to be proved by everything that we have been saying, and that is that the time intervals must be related to speeds. If these intervals are based only on what has happened during a given time, they will be nothing but spatial inclusions. They will have a spatial relationship and not a temporal one. For instance, the drawings of the water as it pours from the top glass into the bottom can be ordered on nothing other than a spatial basis. But to go from the spatial to the temporal, we must

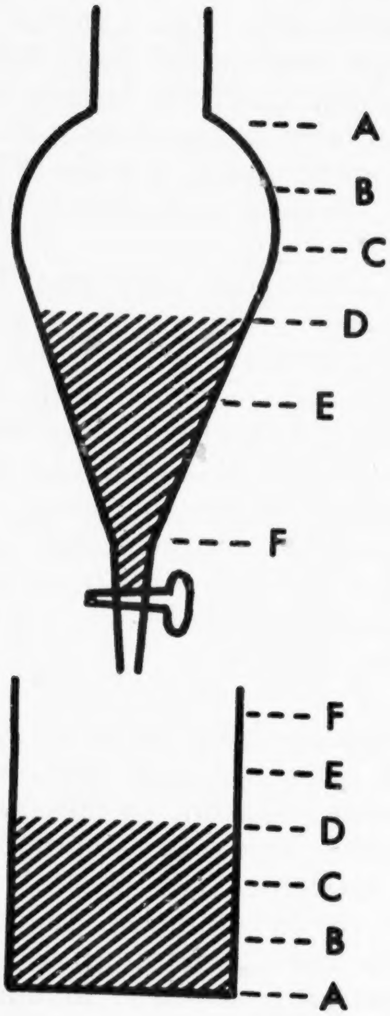

Figure 11

establish a relationship between the space that has been covered -- or in more general terms, the work that has been done, the number of events, for instance, or simply whatever has gone on during this time -- and the speed with which it was done. This is the sense of the conclusion I have reached: time is a coordination of speeds; space is a coordination of displacements.

PART II

COGNITIVE DEVELOPMENT IN CHILDREN: SELECTED PSYCHOLOGICAL REPORTS

AMERICAN COGNITIVE STUDIES: A REVIEW

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Following Piaget's opening remarks at Cornell University this paper was delivered for the purpose of summarizing American cognitive studies. The emphasis is on two current approaches to the study of cognitive growth in children--a modified stimulus-response approach and the approach serving as the basis for the research effort in the Center for Cognitive Studies at Harvard University under the direction of Jerome Bruner. Similarities and differences in these two approaches and experimentation representative of each approach are presented.

Of recent concern to educators, particularly to curriculum builders and innovators, are instructional programs designed to nurture meaning, understanding, and concept formation in students at various school levels. Part of the attention has been given to the "structure of the subject matter" which students are to learn. Each subject is held to have a structure, a logic, a beauty, a "rightness" unique to itself which in large measure should serve as an organizational framework for curriculum decisions.

But another set of factors, the developing cognitive abilities of children--the learners--are also relevant in making school curriculum decisions. As Almy put it in a recent paper, "Another trend in curriculum experimentation involves attempts to break down specific disciplines into their component parts, and to match the learning of these to the developing intellectual abilities of the children." (Almy, 1964, page 9) It is in this regard that cognitive studies by psychologists and educators are becoming increasingly important. And so we encounter Bruner's embracing hypothesis which serves as the basis for his provocative book, The Process of Education: "Any subject can be taught effectively in some intellectually honest form to any child at any stage of development." (Bruner, 1961, page 33) Knowledge of the relationship, if one can be found, between the learner and what is to be learned--between the cognitive abilities of children at different levels of development and the structure of the subject matter they are to learn-- should permit us to make enormous strides in increasing the effectiveness and efficiency of learning as it goes on in school situations.

This conference has been planned to consider the implications of cognitive studies for planning science curricula at the elementary and junior high school levels. As such it addresses itself, in this specific sense, to the general quest for the relationship between the cognitive development of children and the structure of the subject matter to be learned.

Speaking as an educational psychologist, I shall attempt to summarize, all too briefly, some recent psychological approaches to and studies of cognitive development or, if you will, concept formation in children. After a brief mention of some trends in this area, I shall concentrate on describing a modified stimulus-response model approach to the understanding of concept formation as represented in the work of the Kendlers and others and an analysis of children's cognitive development as represented in the formulations and research of Bruner and others. These approaches are essentially "psychological" in character and do not constitute a frontal attack on the problem of relating school instructional programs to children's cognitive development.

The influence of theories and methodology developed by Piaget in Europe and Guilford in the United States, emphasizing the qualitative (as opposed to the quantitative) aspects of cognitive functioning, is discernible in recent studies. The emphasis is on the process of cognitive functioning rather than the potential for it. Methodologically the trend has been away from paper and pencil tests, aimed at quantifying, to the "clinical method," which involves interviewing subjects at work on a task. Knowledge about the nature and development of cognitive functioning is inferred from the subject's verbal responses as he is performing the task, solving the problem, or whatever. Emerging studies on the growth of specific concepts, be they in the area of moral, social, mathematical, or science concepts, reflect even more of Piaget's influence. These studies in the main are attempts to test or confirm his finding in a nomothetic sense with more rigorous experimental design, or to apply his theory to new kinds of concepts.

However, S-R psychology is not dying easily and there is a new effort to develop a rationale supporting the proposition that meaningful learning and development of conceptual systems relies heavily on the formation of associations or S-R bonds. I should like to describe current attempts to adapt traditional S-R theory to more complex learning problems, such as problem solving and concept formation, then briefly allude to developmental changes in children's thinking based on this model.

Postman (1962) has traced the development of S-R conceptions about the learning process from Thorndike's single-unit S-R model to current mediational models. A single-unit S-R model viewed learning as the change in the strength of associative connection between an external stimulus and response. It is a single unit model because no assumptions are made about events intervening between the external stimulus and response.

According to a mediational model, the external stimulus and the overt response are terminal points in a more complex chain of events. The external stimulus (S) evokes an implicit response (r) which embodies the discrimination or classification of the stimulus by the learner. The occurrence of the implicit response changes, or adds to, the stimulation by providing an implicit cue (s) to which the overt response (R) is associated. Thus, the formula for the single-unit model is S-R, that for the mediational model is S-r-s-R. The mediational model makes it possible to assume that responses are associated not only with specific physical stimuli, but also with the meanings and contexts belonging to these stimuli.

I should like to describe an experimental situation which tests the adequacy of the mediational S-R model against the traditional S-R model. The experiment involves reversal and nonreversal shifts in the learning of concepts. Concept formation is here defined as the discrimination of a common critical feature in a variety of contexts. That is, we infer that an individual has formed a concept when he is able to identify, or to respond to a common property shared by a number of objects or events.

Subjects are given the task of sorting a pack of cards into two piles. On each of the cards is a triangle. The triangles vary along two dimensions--size (large or small) and color (red or green). Thus, there are four possible combinations: large green, small green, large red, and small red. The cards are to be sorted into two piles identified by the following models or exemplar cards: (a) a large green triangle and (b) a small red triangle. During the first stage of the experiment, the relevant characteristic which determines the correct assignment to the piles is size. Thus, all large triangles regardless of color must be matched to model (a) and all small triangles regardless of color must be matched to model (b). The subject's choices are differentially reinforced (called right or wrong) and training is continued until a criterion of several successive errorless matches has been achieved.

Then the subjects are divided into two groups, and each group has to learn a second concept. The first group has to learn the reverse of the first concept, i.e., all large triangles regardless of color must be matched to model (b), and all small triangles regardless of color must be matched to model (a). Whereas in the first stage large went with large and small with small, the reverse relationship is now true. Hence, this group is called the reversal shift group. The second group has to learn to sort the cards on the basis of a new dimension which had previously been irrelevant--color. That is, all green triangles regardless of size must now be matched to model (a), and all red triangles regardless of size must be matched to model (b). This is the nonreversal shift group.

According to a single-unit S-R model, we would expect the nonreversal shift to be learned more quickly In the first stage of the experiment, the response of matching sizes directly has been consistently reinforced, and this habit should interfere maximally with the acquisition of the new habit by the reversal shift group of mismatching sizes. The nonreversal shift group, on the other hand, has to learn to use a new dimension (color), and interference from the old habit would be expected only on half of the trials (i.e., that half of the cases in which matches according to color and size do not coincide).

With college students as subjects, however, the reversal shift is learned reliably faster than the non-reversal shift. This finding falls into place if we assume that what is critical for the speed of concept formation is the mediational response (r) evoked by the stimuli. During the first part of training, the differential response mediating the correct choice is size. Thus for the reversal shift group, the appropriate mediational response--differentiation according to size--is already available and all that has to be changed is the nature of the overt response. For the nonreversal shift group, a new mediational response--differentiation according to color--has to be acquired, although half the time the old overt responses remain correct. The large differences consistently obtained in favor of the reversal shift group indicate that the transfer of mediational responses is far more significant in concept learning than is the transfer of specific overt responses.

Now all this is an interesting theoretical discourse, but for our purposes it is interesting to note that comparisons between reversal shifts and nonreversal shifts yield diametrically opposite results with animals and adult human subjects. Whereas for adults the reversal shift is much the easier, the opposite is true for rats. Recent research by the Kendlers (1962) suggests that the single-unit model may be appropriate to inarticulate organisms with limited symbolic capacities, and the mediational model to organisms capable of verbalization and related symbolic acts.

To pursue this matter a bit further, the Kendlers conducted an experiment with kindergarten children, using brightness and size as the critical dimensions of discrimination. No difference was found in making reversal and nonreversal shifts when the group was considered as a whole. However, when the subjects were divided into slow and fast learners on the basis of their performance on the initial problem, it was found that the reversal shift was easier for fast learners and the nonreversal shift was easier for slow learners. A reasonable interpretation is that for the fast learners the verbal and symbolic processes essential in mediational control had developed to a higher degree than for the slow learners. A further confirmation of this general analysis is provided by the fact that the percentage of subjects doing better on reversal shift problems as compared with nonreversal shift problems increases steadily from three to ten years of age.

Other investigations relating the development of conceptual systems and associative learning include one by Bousfield, Esterson, and Whitmarsh (1958). Using a word-list recall task to determine the amount of associative clustering and the preferred basis for clustering (color vs. function) in children from third grade to college, they found that older subjects had better recall and showed a greater amount of conceptual clustering than did younger subjects. This suggests the increasing integration of cognitive structure with age. By cognitive structure is meant an individual's organization, stability, and clarity of knowledge in a conceptual area or subject-matter field relative to meaningful new learning tasks in this field.

In another study, (Akutagawa and Benoit, 1959) this one involving paired-associate learning, age was found to be a far more significant factor than IQ in the ability to learn very simple associations, although the importance of intelligence did increase as the learning task became more complex. It appears that lower levels of associative learning are determined more by the gross amount of experience than by intelligence. Like so many other cognitive abilities, the ability to form new associations develops as a function of experience, probably because experience expands the cognitive structure which, in turn, facilitates the learning of new associations. In Ausubel's terms there are more relevant subsumers available. At any rate one can make a convincing case for the importance of experience as a determinant in the growth of learning ability and concept formation. The question of whether or not one can force-feed this experience by providing more stimulating situations in school settings remains to be answered.

In summing up the current conceptions of S-R theory as applied to more complex learning such as concept formation, it appears that a single-unit model of stimulus-response association is not adequate. However, the necessary extensions and modifications of the model can be accomplished within the framework of S-R theory; that is, the acquisition and utilization of mediational responses are assumed to be governed by the basic laws of associative learning. S-R theory is still alive in cognitive studies.

Now consider another approach to the course of cognitive growth serving as the basis for the research effort in the Center for Cognitive Studies at Harvard University under the directorship of Professor Jerome Bruner. (Bruner, 1964) Bruner's position is that cognitive growth in humans is dependent on the emergence of two forms of competence--representation and integration. That is, during the developmental process children must acquire ways of representing the recurrent regularities in their environment as means for dealing with information on the one hand, and they must organize acts of information processing into a higher order of cognitive structure to permit long-range problem solving efforts--efforts that transcend the immediate and link past to present to future.

Three modes of representation are identified--enactive representation, iconic representation, and symbolic representation. They emerge in order during the child's development. Enactive representation refers to representing events through appropriate motor responses, by action alone. According to Bruner " . . . iconic representation summarizes events by the selective organization of percepts and of images, by the spatial, temporal, and qualitative structures of the perceptual field and their transformed image. Images stand for perceptual events in the close but conventionally selective way that a picture stands for the object pictured." (Bruner, 1964, page 2) Symbolic representation involves translating experience into symbol systems. Using these symbol systems as cognitive instruments it is possible for the child to transcend immediate experience, to systematically transform the regularities of experience with far greater flexibility and power than before--in short, to increase his abstraction abilities and long-range problem solving efforts. And so we see in the developing child a successive emergence of action, image, and word as the vehicles of representation--reminding us of the pre-operational stage, the stage of concrete operations, and the stage of formal operations suggested by Professor Piaget.

Language development in children between four and twelve years of age comes to be an important cognitive tool--an increasingly important implement of knowing. Much of the research effort at the Center for Cognitive Studies is focusing on the transition from iconic representation to symbolic representation. This research appears particularly pertinent here in that it corresponds roughly to the period in which children are attending the elementary and junior high school. It would seem that a description of some experimentation bearing on the nature of representation and particularly upon the transition from its iconic to its symbolic form is in order.

The first experiment, by Bruner and Kenney, (Bruner, 1964) involves nine plastic glasses aranged so that they vary in three degrees of diameter and three degrees of height. They are presented to the child in this ordered arrangement on a piece of cardboard. The subjects are five, six, and seven year old children. The experimenters remove one, then two, then three glasses from the display--each time asking the child to simply replace them. The children are also asked to describe how the glasses in the columns and rows are alike and how they differ. Next, the glasses are scrambled and the children are asked to replace the glasses to make something like what was there before. Finally, the glasses are scrambled once more, but this time the shortest, thinnest glass is placed in the southeast corner; (it was formerly in the southwest corner). Again the child is asked to make something like what was there before, leaving the one glass where the experimenter had put it. This completes the experiment.

There is no difference among five, six, and seven year olds in the ability to replace glasses taken from the display or in rebuilding the display once the glasses have been scrambled (but without the transposed glass). The only difference is that the older children are quicker. However when the single glass is transposed (i.e., moved from the southwest to the southeast corner with instructions to leave it there) most of the seven-year-olds succeed but hardly any of the five and six year olds. The latter, according to the experimenters, seem to be dominated by an image of the original display. "They try to put the transposed glass back where it belongs, to rotate the display so that it will be as it was before . . . In several instances the five and six year olds tried to reconstruct the old display by building right over the transposed glass." (Bruner, 1964, page 5) For the seven year old the transposition task is more a problem that requires reckoning, not simply copying. He is more likely to talk to himself about "where this should go."

On the task of describing how the glasses in a row and in a column were alike and how they differed, children answered in three distinctive linguistic modes. One was designated dimensional, singling out two ends of an attribute--for example, "That one is higher and that one is shorter." A second was designated global. For example, of the glasses differing only in height, the child would say, "That one is bigger and that one is little." The same words could be used to describe any dimension of any magnitude. The third was designated confounded usage. That is, a dimensional term and a global term are used together. For example, "That one is tall and that one is little." When all three ages are lumped together, the children who used confounded descriptions were twice as likely to fail on the transposition task as those who described the differences and similarities in rows and columns in either dimensional or global terms. Now the significant comparison here is that the descriptive language the children used had no relation to their performance on the untransposed scrambled display task, whereas it did have on the transposed task.

Translated into terminology of iconic and symbolic representation, the results of this experiment are highly suggestive. It would appear, for example, " . . . that children who use iconic representation are more highly sensitized to the spatial-qualitative organization of experience and less to the ordering principles governing such organization. They can recognize and reproduce, but cannot produce new structures based on rule." (Bruner, 1964, page 5) They are, in fact, dominated more by image and reproduction than by symbol and translation or transposition. Also, the language brought to bear on a task by children characterized by iconic representation seems inadequate as a tool for ordering.

It follows that improvement in language at any given age should aid problem solving of this type. Perhaps the best way to improve understanding in elementary science is to improve language skills. But Bruner suggests that it is reasonable to suppose that activation of language habits that the child has already mastered might improve performance as well. This activation can be accomplished in two ways. The child can practice "saying" the description of something before him that he must deal with symbolically. Or he can say his description in the absence of the things to be described. The latter approach has the advantage of avoiding the dominance of a perceptual-iconic representation which might inhibit the operation of symbolic processes.

The importance of this point is illustrated by Natadze's study of seven year old Russian children. (Natadze, 1963) These children, who could successfully list the essential taxonomic characteristics of fishes and mammals, would still persist in calling a dolphin a fish. They were not influenced by the contradictory information regarding the mode of respiration and propagation employed by the dolphin. Rather, the dolphin's external characteristics, i.e., the perceived visual image, eclipsed to such an extent the counterposed essential non-visual features, that the seven year olds did not sense the contradiction.

The effects of saying before seeing are demonstrated in an experiment reported by Frank. (Bruner, 1964) It involves altering the behavior of children who are incapable of conserving liquid volume across transformation in its appearance. Piaget has shown that when children between the ages of four and seven are presented two identical beakers equally full of water, they will no longer judge the water equal if the contents of one of the beakers is poured into a beaker that is either wider or thinner than the original one. If the new beaker is thinner, the children say there is more water because the water level is higher. If the new beaker is wider, they will say it has less because the water level is lower. In Frank's experiment, conducted with four, five, six and seven year olds, the subjects were first presented with this classical conservation experiment. Next, a wider beaker of the same height is introduced and the three beakers are concealed by a screen, with only their tops showing. The experimenter pours from one of the two identical beakers into the wider beaker. Without seeing the water level, which is hidden by the screen, the child is asked which beaker has more to drink, the wider beaker or the beaker identical to the one from which the water had been poured--or if they have the same amount.

The results are compared across the age levels for the classical conservation experiment (unscreened) and the screened experiment. As compared to the unscreened experiment; in the screened experiment, the four year olds increase in correct equality judgments from 0% to 50%; the five year olds from 20% to 90%; and the six and seven year olds from 50% to 100%.

Then the screen is removed and the children are asked the same question. All the four year olds revert back to their initial judgment made in the original unscreened experiment. It is as though the perceptual display overwhelms them and they decide that the wider beaker has less water. But almost all of the five year olds stick to their judgment of equality. And all of the six and seven year olds hold to their judgment of equality.

A few minutes later the experimenter repeated the unscreened conservation experiment--this time using a tall thin beaker along with the two identical ones. The four year olds seem unaffected by their previous experience and none of them is able to grasp the idea of invariant quantity in the new task. Recall that among the five year olds, 20% showed conservation in the original unscreened experiment, 90% with the screening procedure, and almost the same percentage (about 80%) when the screen was removed. In the new unscreened experiment 70% of the five year olds show conservation. Among the six and seven year olds, 50% showed conservation in the original unscreened experiment and 100% in the screened experiment (holding to that percentage even when the screen was removed). In the new unscreened experiment 90% of the six and seven year olds show conservation, i.e. give correct equality judgments. Control groups doing just the two unscreened experiments without the intervening screened experiment showed no significant improvement in performance. Frank's demonstration is a good example of the effects of "perceptual instruction" in improving problem solving of this type, perhaps of accelerating the transition from the iconic to the symbolic mode of representation.

Another experiment, reported by Nair (Bruner, 1964), involving "conservation" demonstrates the importance of language as a shield against the visual displays as seen in the Frank experiment. Using only five-year olds as subjects, Nair transferred water from one rectangular clear plastic tank to another that was longer and wider. The water level is, of course, lower in the second tank and ordinarily a five-year old will say there is less water in it. Nair had a toy duck swimming in the initial container, and when the water was poured into the new container, she told the child that the duck was taking the water with him.

The arguments offered by the children to support their judgments were classified into three categories: perceptual (having to do with the height or width of the water); action-oriented (the water was only poured, or the duck took the water with him); and transformational (this argument invokès the reversibility principle, e.g., if you poured the water back into the first container, it would look the same again). Now the significant finding here is that of the children who thought the water was not equal in amount after pouring, 85% used perceptual arguments to support their judgment. Of those who recognized the equality of the water, 67% used non-perceptual arguments. Apparently to achieve success in a conservation task children need an internalized symbol system to insulate their thought processes from the misleading perception of the visual display.

The studies cited represent only a sampling of current research on cognition. Studies on other concepts such as volume, fullness, how children group objects and events into equivalence classes, etc. could be reported almost indefinitely. On the basis of this kind of evidence Bruner and others suggest that we can most fruitfully look upon cognitive growth as consisting in part in the development of systems of representation as means for dealing with information. To quote Bruner, "the growing child begins with a strong reliance upon learned action patterns to represent the world around him. In time, there is added to this technology a means for simultanizing regularities in experience into images that stand for events in the way that pictures do. And to this is finally added a technology of translating experience into a symbol system that can be operated upon by rules of transformation that greatly increase the possible range of problem solving." (Bruner, 1964, page 14)

As the symbol system we call language develops into a hierarchial system and becomes more internalized, it assumes greater importance as a guide or set of abstract rules for organizing events. A simple experiment by Huttenlocher (Bruner, 1964) with children between the ages of six and twelve, illustrates the increased power for organizing acts of information processing into more integrated and long range problem solving efforts. Two light switches are before the child; each can be in one of two positions. A light bulb is also visible. The child is asked to tell, on the basis of turning only one switch, what turns the light on. There are four ways in which the presentations are made. In the first, the light is off initially and when the child turns a switch, the light comes on. In the second, the light is on and when the child turns a switch, it goes off. In the third, the light is on and when the child turns a switch, it stays on. In the fourth, the light is off and when the child turns a switch, it stays off.

Note that there are different numbers of inductive steps required to make a correct inference in each task. The simplest condition is the off-on case. The position to which the switch has just been moved is responsible for the light going on. In the on-off condition two connected inferences are required. The position to which the switch has just been moved must be rejected and the original position of the switch that has been turned is responsible for lighting the bulb. In the on-on case three connected inferences are required. The new position and the original position of the turned switch must be rejected and the present position of the other switch is responsible. The off-off case requires four steps: rejecting the present position of the turned switch, its original position, and the present position of the other switch, finally accepting the alternative position of the unturned switch. The nature of the individual steps is the same and what is required in the more complex cases is the ability to integrate these steps consecutively.

Huttenlocher found that the six year olds do not differ significantly from the twelve year olds in the one-step case--the on-off display. However, in general, the more inferential steps the six year old must make, the poorer his performance. By age twelve, however, the difference in performance among tasks requiring one, two, three, or four connected inferences is not significant.

This experiment, and others like it, suggests that as children develop they are able to use indirect information based on forms of information processing other than the act of pointing to what is in the immediate present. They are able to abstract, to hypothesize, to go beyond the information given. And they seem to be able to cumulate information into a hierarchically organized cognitive structure that can be operated upon by rules that transcend those of association. This system of processing, organizing, and integrating information depends upon the translation of experience into symbolic form.

To summarize, I have attempted to review two current approaches to the study of cognitive growth in children and to describe some experimentation representative of each approach. Although the approaches have a different theoretical orientation the relevance of the development of a symbol system, particularly language development, to the understanding of cognitive structure is common to each one.

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EXPERIENCE AND COGNITIVE STRUCTURE

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Mink, formerly of Cornell University and now with the Xerox Corporation, discusses research on experience and cognitive structure using human and subhuman species. The relationship of Ausubel's subsumption theory to Piaget's developmental approach is explored. Throughout, the inadequacy of a strict interpretation of an S-R model to the exclusion of cognitive structure variables is emphasized. The paper concludes with a brief discussion of a research project at Cornell University and a model for researching the development of the learning process.

The relationships which exist between the laboratory study of learning and learning in the classroom are not easy to identify. In some sense experimental research in learning forms a foundation for research in the classroom context, but most laboratory findings are established under conditions which are not reproducible in the classroom. However, many recent studies of concept formation are approaching very directly problems faced by educators. The work of Bruner, Ausubel and Piaget promises to provide findings appropriate for pedagogical purposes. Their studies have been conducted with human subjects and seem to point in similar directions. Presently available data indicate the existence of cognitive structure, meaningfully organized and functionally related to the structure of knowledge in various disciplines. The foregoing assumption has always been implicit in any naive theory of behavior, but until recently, many scientific approaches to these assumptions have been impotent. The task, as I see it, is to be able to account for the role of experiential background on the existing cognitive structure in order to establish appropriate learning experiences - present and future. In addition, we will be better able to apply the emerging principles to the entire educational sequence of a person with maximum effectiveness.

The conceptualizations of Ausubel and Piaget have wider applicability than structure in any given academic discipline. For example, when Piaget discusses a schema, he is inclusive enough in his conceptualization to consider a reflex action that one might observe in a lower organism or a neonate as well as the complexities of problem-solving behavior in a mature human. Whereas, most psychologists interpret the behavior of lower organisms in terms of some response to a persistent imposing stimulus, I would like to suggest that perhaps one could reinterpret many research findings with subhuman species in terms of a cognitive structure paradigm similar to those of Bruner, Ausubel, and Piaget.

You will recall that when the Kendlers tried their reversal shift experiments with small children and rats, the S-R model proved best to explain the data. However, when they used college students as subjects, the reversal shift group mastered the criterion measure most effectively supporting the validity of a mediational model where "meaning" mediates. Their data not only suggest differences in cognitive functioning between species but it also suggests differences within a species where species members differ in developmental level. I am acutely aware of the pitfalls of comparative psychology, but for purposes of general discussion and in order to focus attention upon the possible roles of experience and ontogenetic development in a paradigm of learning, I will refer to some research findings drawn from research on other animals as well as humans. I will ask you to do some divergent speculation regarding the implications for concept formation.

Hebb, Williams and others

The essence of this body of experimentation is that learning occurs in two stages (Hebb, 1953). These stages vary in nature in that the first stage is slow and arduous and the second stage is relatively fast and facile. The focus of much of their research has been the interaction between early learning and late learning. Since Tryon (1940, 1942) first demonstrated his effectiveness in rearing a selected strain of good maze-running rats, psychologists have had the necessary instruments for studying the relative influences of early experience and learning upon future performance using heredity and experience as independent and interacting variables. Carr and Williams (1957) suggest that early experience has a differential effect upon later learning. Burt and Howare (1957) point out the relative influence of heredity and environment. It has been demonstrated that if bright and dull maze-running strains of white laboratory rats are raised in normal environments the bright strains will, as one would predict, be the most efficient maze runner. However, bright rats raised in deprived environments are inferior to dull rats raised in enriched environments, and dull rats raised in enriched environments are equal to bright rats raised in enriched or normal environments in terms of maze-running ability. In another study, Hebb (1949) describes the efforts of adults who have gained vision for the first time as they try to discriminate between a circle and a triangle. Even when they are told and shown the difference, they do not respond accurately. Only after much practice can they successfully make these discriminations, which reaffirms the necessity for appropriately related early experiences or in Piaget's terms, appropriate schemata.

Thompson and Melzack (1956) have demonstrated that Scottish terriers raised in the homes of laboratory workers are superior when compared to those raised under relatively stimulus free laboratory conditions. Later comparisons demonstrated that the dogs raised in the enriched environment were superior in social and competitive situations. The laboratory raised dogs demonstrated much more spontaneity, but less ability to relate or organize their behavior in ways appropriate to varying situational contexts. This latter phenomenon could be explained in terms of Ausubel's conceptualization of cognitive structure, i.e., the existing and established cognitive framework with particular organizational properties does not exist because of limited prior experience. In short, the experimental dogs lacked the cumulatively acquired, hierarchically organized and established body of knowledge which is organically related to the new learning task, which was avoiding common obstacles. Note that I did not say that I thought the dogs were learning another set of discrete connections influenced by a recently experienced constellation of stimulus-response connections. If this were the case, one would have hypothesized rather consistent trial and error learning between the experimental and control groups at a comparable level. It is difficult to explain the persistent inappropriate behavior of the laboratory dogs using an S-R model. Rather, the relevant transfer paradigm includes cognitive structure variables relating to situational knowledge, i.e., clarity, stability, generalizability, inclusiveness, cohesiveness, and discriminability. From the point of view of Ausubel's subsumption theory of learning, Melzack's laboratory dogs act very much as if they are lacking "clear, stable and suitably organized" cognitive structure. Appropriate subsuming concepts - existing concepts in cognitive structure - are not available and thus a specific social or competitive instance makes the laboratory dogs seem "unbelievably stupid." One can assume that these laboratory dogs raised under conditions where they did not experience common hazards or social situations, were - in the test situation - involved in early learning which necessitated the mastery of simple functions and the acquisition of specific informational data. Because the dogs lacked prior experience, there was no existing appropriately related cognitive structure. Their learning was at a stage of simple rote acquisition of discrete experience. Thus, one observes adult dogs completely at the mercy of their environment.

Harlow and his students at Wisconsin (1961, 1959, 1958, 1954, 1943) have also been investigating the effects of early experience using the Macaque (Makak) monkey. Of all their studies, two are most interesting to me. They are both related theoretically to the "critical periods" hypothesis. Many investigators - psychologists and ecologists (Conrad Lorenz - 1958, Edhard Hess - 1959) alike - from observing the development of swimming in salamanders, mating in gulls, pecking in chicks, behavior of goslings - have reported the probable existence of phases in the maturing process of the organism during which the occurrence of certain stimuli will elicit these complete behavioral patterns. However, if something is done to interfere with the presentation of appropriate stimuli and the acting out of related behavior during the critical developmental period, the salamanders will not swim, the chick will not peck and the ducks won't fly - apparently, certain behavioral patterns can be acquired only during certain developmental periods. In addition, during these same periods, intensive permanent learning can take place which is incongruent with natural preferences.

Chicks will reverse a natural preference to yellow for a learned preference to blue and ducklings will follow the rustling of a man's movement in lieu of the typical preference for the mother mallard.

Harlow (1961) observed this same phenomenon in two entirely different ways. First, he observed that the macaque developed the ability to discriminate between various geometric forms at about the age of five months. He found that if one waited until the Macaque had mastered the discrimination tasks and then performed cortical lesions that relearning was difficult if, indeed, possible at all. However, he found that if lesions were performed early in the Macaque's life - say at five days of age - the Macaques with lesions mastered the discrimination tasks with as great or greater facility than the controls. In short, the findings remind one of the critical periods hypothesis. To me this experiment is as suggestive as the imprinting of following behavior in Conrad Lorenz's mallards or the reversing of color preference in Hess's five-day old chicks.

Harlow's second experiment dealt with the social behavior of the Macaque. He found that, if the young monkeys were isolated from peers, upon reaching maturity they were incapable of executing the mating patterns. Males, particularly, would not mount females and females had a low frequency of conception even though they were exposed to the very persistent efforts of healthy males.

The significant aspect of the foregoing data is that, just as lack of appropriate early experiences can cause an adult dog to act stupid in a "theoretically" simple social situation which could "theoretically" be mastered by simple trial and error learning, so the presence of cognitive structure can form the basis for idiosyncratic behavior in adulthood. The interesting feature of the data and the common denominator of the studies reviewed is that each is in some way incongruous with the rudimentary S-R model. Each suggests that a more comprehensive theory is necessary in order to explain the data. Of the currently available theories, the approaches which seem to encompass the foregoing studies are theories which allow for the organization of cognitive structure as well as for some kind of modified critical periods or stage hypothesis. The two systems which are most appealing at this point are: Ausubel's subsumption theory of learning and several conceptualizations drawn from Piaget's theory. Let's look first at subsumption theory.

Ausubel's Subsumption Theory

Ausubel's research deals with cognitive structure and the facilitation of meaningful verbal learning. His entire research program is based on the premise that existing cognitive structure, that is, an individual's organization, stability, and clarity of knowledge in a particular subject matter field at any given time, is the principal factor influencing the learning and retention of meaningful new material. If existing cognitive structure is clear, stable, and suitably organized, it facilitates the learning and retention of new subject matter. If it is unstable, ambiguous, and disorganized, it inhibits learning and retention. Hence, it is largely by strengthening relevant aspects of cognitive structure that new learning and retention can be facilitated.

The model of cognitive organization proposed by Ausubel for the learning and retention of meaningful materials assumes the existence of a cognitive structure that is hierarchically organized in terms of highly inclusive conceptual traces under which are subsumed traces* of less inclusive subconcepts. The major organizational principle, in other words, is that of progressive differentiation of trace systems of a given sphere of knowledge from regions of greater to lesser inclusiveness, each linked to the next higher step in the hierarchy through a process of subsumption.

Thus, as new material enters the cognitive field, it interacts with and is appropriately subsumed under a relevant and more inclusive conceptual system. The very fact that it is subsumable, that is, relatable to stable elements in cognitive structure, accounts for its meaningfulness and makes possible the perception of insightful relationships. If it were not subsumable, it would constitute rote material and form discrete and isolated traces. Thus, one can see why it is that recently acquired concepts and facts are able to be easily differentiated from their relationship with the overriding cognitive structure. However, this state of affairs is short lived. Gradually, facts not appropriately related to the overall cognitive structure erode away and principles related to the existing structure are subjected to the conceptualizing trend in cognitive organization. Ausubel states: "Because it is more economical and less burdensome to retain a single inclusive concept than to remember a large number of more specific items, the import of the latter tends to be incorporated by the generalized meaning of the former. When this second or obliterative stage of subsumption begins, the specific items become progressively less dissociable as entities in their own right, until they are no longer available and are said to be forgotten." (1962, p. 5)

Neidt (Ahmann, 1957) in a study of retention of facts and principles from an introductory psychology course, made an interesting finding which relates to the foregoing theory. He developed a measure of factual knowledge and a measure of principles taught during the course. As one might hypothesize, the students performed well on both tests at the completion of the course. If anything, they were a little hazy on the principles. However, as he continued testing throughout the succeeding four years of college, he discovered a constantly declining curve of fact retention and an accelerating curve of principle retention.

Much more salient than laboratory types of learning situations, school learning requires the incorporation of new concepts and information into an existing and established cognitive framework with particular organizational properties. The acquisition of adequate structure has been shown to depend upon two factors:

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*The term "trace" is used here simply as a hypothetical construct to account for the continuing representation of past experience in the nervous system and in present cognitive structure. No assumptions are made regarding the neurophysiological basis of the trace or regarding psychophysiological correlations.

(a) using for organizational and integrative purposes those substantive concepts and principles in a given discipline that have the widest explanatory power, inclusiveness, generalizability, and relatability to the subject matter content of that discipline; and (b) employing those methods of presenting and ordering the sequence of subject matter that best enhances the clarity, stability, and integratedness of cognitive structure for purposes of new learning and problem solving.

The task of identifying the particular organizing and explanatory principles in the various disciplines that manifest widest generality and integrative properties is obviously a formidable and long-range problem and should be derivable from what Bruner has called the structure or logic of the subject. Once the substantive organizational problem (i.e., identifying the basic organizing concepts in a given discipline) is solved, attention can be given to (b), the programmatic organizational problems involved in the presentation and sequential arrangement of component units. Irrespective of the subject matter field, two principles concerned with presentation of content are suggested -- the principle of progressive differentiation and the principle of integrative reconciliation.

When subject matter is presented in accordance with the principle of progressive differentiation, the most general and inclusive ideas of the discipline are presented first, and are then progressively differentiated in terms of detail and specificity. Even though this principle seems rather self-evident, it is rarely followed in actual teaching procedures or in the organization of most textbooks. The more typical practice is to segregate topically homogeneous materials into separate chapters, and to present them throughout at a uniform level of conceptualication in accordance with a logical outline of subject matter organization. In most instances, students are required to learn the details of new and unfamiliar disciplines before they have acquired an adequate body of relevant subsumers at an appropriate level of inclusiveness. Organization of the curriculum in spiral fashion is more compatible with the principle of progressive differentiation.

Progressive differentiation in presenting subject matter is accomplished by using a hierarchial series of organizers (in descending order of inclusiveness), each organizer preceding its corresponding unit of detailed, differentiated material. In this way not only is an appropriately relevant and inclusive subsumer made available to provide ideational scaffolding for each component unit of differential subject matter, but the various units in relation to each other are also progressively differentiated, i.e., organized in descending order of inclusiveness. In sequential school learning, knowledge of earlier-appearing material in the sequence plays much the same role as an organizer in relation to later-appearing material in the sequence. It constitutes relevant ideational scaffolding.

Organizers are also expressly designed to further the principle of integrative reconciliation. They do this by explicitly pointing out in what ways previously learned, related concepts in cognitive structure are either basically similar to or essentially different from new ideas and information in the learning task.

From his researches using this approach, Ausubel concludes that sequential organization of subject matter, combined with the use of appropriate advance organizers, can be very effective in classroom learning because each new increment of knowledge serves as an anchoring post for subsequent learning. The general paradigm of sequential organization is not from easy to difficult, but from general to specific.

In reviewing Ausubel's work, one must ask the question: "In order to build mastery of a subject field whether it be self-other relationships or chemistry, must one first acquire through simple, rote memory, a number of discrete and seemingly isolated facts and subconcepts before he can construct his first organizers?" If, as material is accumulated, the continuing representation in the nervous system develops an organization which can at the same time represent the structure of knowledge in a discipline and the idiosyncrasy of the person or idiosyncratic representations of the subject matter structure within the person, and if the greater the clarity with which actual structure of the subject field is represented, the greater the potential for subsuming additional related concepts, it would appear than an earlier perhaps more arduous type of learning must precede the first ideational scaffolding. The pedagogical question would be, "At what point in a child's development can he have available the first nuances of organized cognitive structure?" The thought occurs to me that Professor Piaget's concept of the development of schemas is an answer to the nature of early learning. Where Ausubel is concerned with using ideational structure and teaching new organizers to children to use as a cognitive framework for future learning of specifics, Piaget indicates the way in which cognitive structure emerges.

Observe then, if you will, an interesting paradox: in order to be pedagogically sound, one should structure the didactic exposition of subject matter in such a way that he can present to students organizing principles, by which specific facts can be subsumed. The organizers are the most general and inclusive concepts of the discipline. Thus, if one is introducing mechanics in a physics course for the first time, a relevant organizer for leverage problems may well be the concept of balance drawn from experience with algebraic equations. However, where and how does one first acquire the rudimentary concepts necessary to construct the first organizers for a child? Just as in the case of Melzack's dogs, the educator, in order to be effective, requires reasonably adequate experiential backgrounds. Professor Piaget has given us a vast array of interesting data and extremely useful observations, all of which imply orderly development in cognitive functioning given adequate experiential backgrounds. Adequate development not only indicates the integration of relevant concepts within a discipline, but being aware of the similarities and differences between disciplines. His observations regarding the cognitive growth of children have delineated sequences in developmental process with at least two important dimensions: (1) subjective-objective and (2) concrete-abstract.

Basic Notions of Piaget

Let's look briefly at some of Professor Piaget's theoretical concepts.

Adaptive Behavior

Schemata. For Piaget, schema means a repeatable behavior pattern. Thus, a representation of the observable behavior pattern exists in the cognitive structure and forms the basis for future cognitive and behavioral functioning in future situational contexts. In some ways one could call a schema a response in the sense that it is repeatable and reliable in a specific situation. However, a schema is expandable or potentially always in the process of becoming so. I am reminded of the effect of throwing a stone in a pool of water and watching the growth of an ever-increasing ring of concentric circles. In the first month in a child's life, the schemata are evidenced by simple reflexes which are essentially exercises for the sake of selves. The fact that they have influence for survival may be more or less irrelevant. But, schemas can range from the brief simple sucking sequence of the neonate to the level of complex problem-solving strategies of a superior adult. Schemata are then cognitive representations of a class of similar action sequences identified by Piaget in terms of: (1) functions, and (2) cognitive structure. Functions include schema of prehension, schema of sight, schema of intuitive, qualitative correspondence. (The latter is the strategy by which two sets of elements are assessed for numerical equivalence.) Schemata are cognitive representations of a class of similar action sequences. In cognitive structure, existing schemata subsume future cognitive events or are modified in order to subsume. Thus, "a schema is a cognitive structure which has reference to a class of similar action sequences, these sequences of necessity being strong, bounded totalities in which the constituent behavioral elements are tightly interrelated." (Flavell, 1963)

Assimilation, Accommodation, and Adaptation. If a child who has a schema for pulling wishes to reach an object on the far edge of a rug and does so by pulling the rug towards him, Piaget would say that the behavior was assimilated into existing cognitive structure. Any required behavioral act of a specific nature which is generally represented in cognitive structure by a schema is adapted to by the process of assimilation.

On the other hand, if the organism hasn't a completely relevant schema, then it accommodates, e.g. a girl has a lifting schema and can lift a bag of groceries. Yet, if she encounters the problem of lifting a 500# boulder for the first time, she must accommodate by building the behavior sequences involved in rigging some kind of pulley system. Existing cognitive structure is modified to encompass the modified problem situation. Adaptation is to Piaget a balance of the terms assimilation and accommodation. If one can take into an existing behavior pattern, one assimilates. If one must change his pattern of response, one accommodates. In behavioral terms, this is a very interesting way to observe; one can: (1) either deal with the stimulus or (2) change to meet the situation. In the former instance, it is simply behavior and in the latter instance, it is change in behavior or learning. Here the relevance to Ausubel's subsumption theory is indeed striking.

Cornell Studies

Our project was an outgrowth of an early encounter with a curriculum supervisor when I was working for the Board of Cooperative Educational Services as a school psychologist. The curriculum specialist wanted assistance in the grade placement of certain science activities developed by teachers for elementary school children. The answer to his question was simply not readily available in terms of experimental evidence beyond certain inferences to be gained from the intuitive judgments of teachers and various psychological tests like the Stanford-Binet. It was decided that one of the most useful sets of descriptive information that could be obtained for the educational practitioner would be a comprehensive classification of scientific principles indicating which principles can be understood by children at given stages of mental development. The heart of the proposed research is directed at the question, at which mental age levels are children first able to understand selected science activities?

The study consists of two phases: Phase 1, includes the selection of science activities, identification of the principles being illustrated in terms of their underlying units of structure, construction of criteria measures for understanding the science principles, and selection of relevant independent variables. Phase 1' relates mental age and the units of structure underlying a given science principle to the criterion scores.

Betty McKnight is the project director of the Seneca-Tompkins Board of Cooperative Educational Services project for developing grade level placement of certain science activities. We are presently accumulating data on large samples of children at all age levels inclusive in the K through 6th grades. The mental age range runs over 14 years. What we consistently find is a positively accelerated curve from low to high mental age in terms of the ability of Ss to grasp the concepts taught. Eventually, we hope to be able to take a proposition like Archimede's Principle and identify each substructural unit, e.g., conservation of mass, area, or weight and determine at what stage in development the specific subconcept is available to the relevant schema.

As this study develops, it is becoming apparent that we can develop what will approximate mathematical models describing the course of cognitive development by comparing descriptive curves from various principles and identifying those conceptual units of structure which form barriers for children at specified mental ages. After the models are constructed, one can then test some of the contentions of Piaget's critics with respect to the extent of experiential influences upon the development of the concrete-abstract and subjective-objective dimensions. Eventually, instead of studying the relationships among several continuously measured qualitative dimensions (objectivity, abstract functioning, open mindedness) or several continuously related outcome variables (problem solving, divergent thinking, or critical thinking) one might, with the use of multivariate procedures obtain correlations which serve as additional building blocks for the construction of a potentially compelling representation of the overall interdependency of the two sets of measures. One might thus be able to construct a process model of intellectual growth over the developmental years. One would identify events occurring in various stages. The elements of the model would be the probabilities of membership in different states of a random variable for different stages or times, and the tables of conditional probabilities, called transitional matrices. All the probabilities and conditional probabilities required would be estimated from research data by frequency counts. If a good description of the development of learning processes could be developed in this way, one could then test the effect of teaching methodologies, experience, and critical periods in a framework of all operating variables.

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LEARNING RESEARCH AND CURRICULUM DEVELOPMENT

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In this paper Cronbach comments on the gap that exists between learning research and curriculum development. Essentially, Cronbach is saying that learning theories have not been particularly helpful in telling the curriculum maker about arranging an optimum sequence of experiences for children in school. Current curriculum reforms are proceeding on foundations other than psychological. He finds Piaget's theory of cognitive development posing similar questions of bridging the gap between cognitive development and curriculum development, but not emerging with clear pedagogical answers.

My role is to provide some sort of bridge between the psychologist and the curriculum reformer. I do not propose to talk about learning theory in any formal sense. It is, I hope, useful to talk about the sorts of assumptions that underlie current curriculum experiments in this country as I gather them from various investigators, and to talk about the gap that exists between learning research and curriculum development.

The learning theory that has been the preoccupation of the American psychologist since the days of Thorndike--SR theory--seems not to have had much impact on the curriculum work that has been going on. The strongest connection between SR theory and current educational experimentation is the work that Skinner has inspired in programming. This certainly has a considerable significance for education, but it has not been closely tied to curriculum studies. While some of those who prepared new curricula have recently asked programmers if programming could be applied to their materials, one would not say that the work of Skinner inspired the curriculum development itself.

A large number of curricula, in science and mathematics particularly, have started on the road since 1958; indeed, a few of them date back to 1952. Some of the innovations and reforms have had nothing to do with the psychology of learning; they have essentially been changes of content. Sometimes the change of content has been purely for the sake of getting up to date. If schools were teaching the wrong theory of physics, they were advised to teach the right theory, to bring the textbook in line with more recent experimental knowledge. Sometimes there has been a shift from subject matter the scientist or mathematician regards as trivial to something he regards as having greater significance. The introduction in the elementary school, for example, of computation on bases other than ten has come not out of any special theory of learning but out of the view that this is a more fundamental way of comprehending arithmetic; i.e., it is better mathematical subject matter. All of these innovations have been approached with the same principles of pedagogy that we have been using for a long time: emphasizing exactly what you want the student to do, teaching him to do it, providing him opportunities for practice, and rewarding him when he does the job right.

But there are some other things going on, rather far removed from what psychologists typically have investigated. These not only embody some new pedagogical or psychological assumptions but are tangential to notions that Piaget has been presenting out of his own investigations. Generally, these ideas arise under cognitive theories of learning, which are less theories than points of view or emphases. It is difficult if not impossible to find any systematic theoretical point of view uniting the concerns of the psychologists in the cognitive camp.

One of our long-standing tenets has been that in any instruction you get better results if the pupil understands what is being presented. "Understanding" has never been elaborated as a concept in SR theory. We saw one form of elaboration of it in Professor Piaget's remarks when he talked about the necessity to capitalize upon the operations that the child has already mastered. Since the operations are in part cognitive, this is saying something about one meaning the term "understanding" might have. But there has been very little theoretical explication of that term.

Prominent in American curriculum development has been a stress on pushing topics downward. As Professor Piaget has said, whenever you tell Americans about some process of development, their first question is "How can you accelerate it?" It has been the spirit of many of the curriculum innovations to say "If this is worth teaching at the ninth grade level, why can't we teach it in the kindergarten?" Many experiments seem to have done precisely that. In the first grade can we teach set theory? coordinate geometry? the force concept? Very often, at least at some level of understanding, that teaching has been successful. It does appear that things can be taught much earlier than we have been teaching them. But in most of these curriculum experiments, the chunks that have been brought down to lower grades have been isolated chunks. We have seen very little yet in the way of a sequential plan that says: We want to teach this topic at this point in the elementary school so that it will be available for use a little later on. (The high school innovations have been much more sequential.)

The notion that you can teach things early obviously is threatened by Professor Piaget's statement about the child's moving through stages, not necessarily with a fixed timing, but with a timing that is very difficult to accelerate. His remark that if you teach something early it may be learned in a false way carries a strong hint that appears to pose considerable problems for both the evaluation of the new curricula and for the theory of instruction that we use. Right now I know of very little information that we could bring to bear on such questions. We may know that after a certain unit, by certain tests, results were rather good; but of the long-term effects of any procedure on the child's structured outlook on mathematics or science we know practically nothing.

In many of the curricula--not the ones I talked about a few moments ago as merely introducing new topics, but the ones that are more radical--there is an emphasis that may be summed up in a phrase such as: "We want to teach the child to think like a scientist" or "like a mathematician." Such notions have been adopted as slogans. They haven't been closely examined, yet they pose some of the most important questions for the educational psychologist. Implicitly they say that we are more interested in indirect learning than in direct learning. It would be easy to understand a proposal to introduce base-two numbers on the grounds that they will be used practically when these pupils as adults get to wiring up computers. This is a direct vocational use. But that is not the proposal of these curriculum makers. Nor does it cover their objective to say that they want to teach the nature of the number system. Behind even that broad objective is the further objective of enabling pupils to cope with mathematical reasoning generally.

This is most obvious in some of the lessons developed by David Page and others, where the child is introduced to a mathematical topic for which there is no mathematical theory. The topic is used for the purpose of the instruction and then abandoned, but through it Page is able to give the children certain types of experiences, for example, the experiences of developing their own technical terms, of beginning to establish their own preliminary assumptions or axioms and seeing what consequences follow. The emphasis is not on the lesson itself, not on the responses practiced during the lesson and reinforced. Rather, the aim is some development of a superstructure of attitudes and intellectual skill. This must have some relation to the development of logical structure that Piaget speaks of, yet so far we have found the connection unclear. Most of the instruction in this vein has been done artistically, without much guidance from theory, because the theory has been far from explicit. The most pertinent American research on learning is the various studies on learning how to learn, learning sets, and the like. Through learning of responses to a number of problems one can also somehow learn to be a better problem solver.

Research on transfer originally emphasized the possibility of learning a solution and then carrying that solution over into a new problem. This is an identical-element transfer of a rather obvious sort, with which many earlier curriculum reforms were concerned. Recent studies point to a second type of transfer in which, as a result of doing a number of problems, you become more competent to understand, to learn about, or to cope with a problem that--on its surface or perhaps in its structure--is different from the types of problems you practiced.

This sort of development of mental structure, if you will, or a way of using the brain--I think none of us knows what it is--seems to be very much the sort of thing Piaget was referring to under the heading of "development." Most of us would be uncomfortable with his separation of "development" from "learning," being convinced that intellectual development does involve learning. Piaget does not deny this. I am only saying that for us this is a somewhat forced distinction because if development involves learning, then in principle it ought to involve instruction. I think all of us would say that there must be experiences we can give at the age of two or seven or 13 that would be suitable to promote this type of development--this second-order transfer. But we are empty of suggestions as to what is most useful.

There is consensus on the necessity of starting with a thorough, concrete familiarity with and operation upon the materials that are to be understood. Hence, there is consistency between American views on teaching math and science and Professor Piaget's theory about the importance of the child's developing, through hundreds of trials, the ability to anticipate what may happen under this or that configuration of events. The risk of teaching the child some concept verbally before he has stored up appropriate images of the relevant objects in motion is a lesson every educator feels he has now learned.

Where one should introduce discovery in this process is more debated. The importance of the child's learning for himself, through discovery, has been much discussed recently in American pedagogy. But investigation on the point has been very limited and most of it untrustworthy. What research seems to say is that leaving the child to discover is not nearly so good as providing him with a guided sequence to maximize the possibility of early discovery. I am convinced that in some cases, the guided sequence will consist simply of telling him what the answer is. But which subject matter should be taught this way, and which through extensive trial and error is an unanswered question.

It is unclear how much one ought to structure the concrete experiences used for instruction. There is a big difference between having a large amount of manipulative experience in some situation, and being in the same situation with a job to be done and a means of deciding when you have done it right. We saw a demonstration a couple of weeks ago of some of the work of Zoltan Deanes, another of the innovators in the elementary classroom. His methodology seems to consist largely of giving the children logical and mathematical forms to play with. He has a large number of games. They can play with these an hour a day forever and presumably with luck will get insight. Some of the games involve--as their outlined mathematical structure--the powers of two. Some involve comparison of form. Some involve multiplication. But there is no course of study; no sequence of paths through which the pupil moves.

Psychologists would tend to say, "Surely there is some definite accomplishment to be achieved here, therefore there must be some best sequence of moving through these activities. There must be some criterion of when the child has had enough experience with this particular activity and is ready to go on." Somewhere between the drill approaches--demonstrate, exercise, reinforce--and the exploratory approaches--enrich the environment and let development occur--there would seem logically to be some optimal curriculum of experiences arranged in some predetermined sequence with intervention and instruction by the teacher systematically regulated. But we do not know nearly enough about such questions. On these questions I, at least, have not seen American learning theories as very helpful.

Now Piaget poses almost the same questions for us. I am not at this point able to say how to go from his position to telling the curriculum maker what he is to do with the seven-year-old. The curriculum maker is concerned with this second type of instruction--the type of instruction that somehow develops mental structures and facilitates the assimilation of new and different material. Here is the objective; on the other hand, here is Piaget's cognitive theory about assimilation. The two seem quite compatible and yet the pedagogical bridge is today quite obscure.

IMPLICATIONS OF PIAGET'S TALKS FOR CURRICULUM

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In this paper Langer discusses the implications of Piaget's theories for curriculum in theoretical terms. These implications are discussed in terms of communication between the "community" and the individual regarding forms of knowledge. This communication, this expression of the forms of knowledge accumulated is seen as influencing the learning task. Several intriguing interpretations and extensions of Piaget's theories are offered.

I have had one major impression throughout this conference, namely, that there is a gap between what the developmental psychologist of cognition is talking about and what the people responsible for the teaching of knowledge are doing. Piaget's and much work of its kind is primarily directed towards studying the development of cognitive functioning, i.e., the cognitive operations which emerge in the course of ontogenesis. These operations determine the forms of knowledge which the organism may construct at a given stage of development.

There is, however, the other side to the problem which has been relatively neglected in the psychology of cognitive development and particularly in this conference, namely, the operations whereby the community communicates the forms of knowledge which it has accumulated to the individual and vice versa. The means of expression utilized determine the forms of knowledge which may be communicated. This is particularly important to curriculum development since the goal must involve the creation of means of communication which increasingly facilitate the task of teacher and student, i.e., learning from each other.

In this connection it becomes necessary to review what is meant by development. Professor Piaget characterizes cognitive development as equilibration rather than maturation, experience or social transmission (cf. Piaget, The origins of intelligence in children; Inhelder and Piaget, The growth of logical thinking from childhood to adolescence). Equilibration is defined as progressive interior organization of knowledge in step-wise fashion. Progressive development is the resultant of the interaction between the functions of assimilation and accommodation.

Now, I have noticed that very little has been said in this conference about accommodation. But it has always been my understanding that it is the relationship between these two functions which makes for either disequilibrium or equilibrium and, consequently, developmental change and stabilization of knowledge. I wonder if one may not suggest that the focus upon the formation of knowledge comes from an emphasis upon assimilation, i.e., with how things can become meaningful and interiorized in the first place, so that they can be dealt with. But if one is also concerned with the exterior fitting of oneself to the community and the community to oneself, then it becomes necessary to focus, in addition, upon organismic accommodation. Accommodation involves adapting to what is there and reorganizing it in such a fashion that it may be integrated with present schemata.

In attempting to understand, on the one hand, what it means to assert that a child is achieving knowledge and, on the other hand, that knowledge is being communicated to him and by him, in the course of development, it is necessary to make certain distinctions. These distinctions will permit me to raise several issues for your consideration with respect to (1) the growth of knowledge, about other things and oneself, and (2) the process whereby knowledge is interiorized and exteriorized, i.e , communicated to oneself and to others.

The first distinction which we must make is between what is knowledge and what is not knowledge. Professor Piaget seems to reserve true, or at least the highest, forms of knowledge to those concepts which arise as a consequence of formal operations. He distinguishes conceptual knowledge, and even that which results from developmentally earlier operations, from those experiences which arise as a result of imaging, perceiving and copying the environment. The development of this latter set of behaviors, according to Piaget, is independent of cognitive development.

A problem which we may raise in passing, and which requires much further empirical investigation, is whether other developmental relationships do not obtain between cognitive and non-cognitive operations, such as imaging. It is particularly likely that relationships such as subordination may obtain where functions such as imagery subserve those of thought. For example, visual imagery of spatial dimensions has often been used in the service of formal theory construction.

The distinction between cognition and non-cognition hinges upon the operations involved. What is taken on in a *passive* fashion, as Professor Smedslund argued, what is *impressed upon* the child is not cognition. It is merely that experience which mirrors the environment. What is *acted upon*, what is created is cognition.

A further distinction has to be made between the means of achieving knowledge and the objects of knowledge. The means towards the formation of knowledge are always acts and they are always *constructive* acts. The assumption is that the organism is always involved in constructive schematization *via* the functional interaction of assimilation and accommodation. Piaget has characterized five stages of cognitive development and the functionally analogous operations which emerge at each stage. The first three are relatively external actions upon or with actualities. There are sensori-motor actions upon things; preoperational actions upon things; and intuitive operations, but now with things.

The first truly internal actions are concrete operations with things. Only at the highest stage of cognitive development do formal operations appear which involve contemplation about things. The last stage permits operating upon operations or the transcendent activity of being conscious of one's consciousness. It becomes possible to reason deductively, formulate hypotheses, and deal with possibilities in addition to mere actualities.

As a consequence of these various schematizing operations different forms of knowledge arise, in the course of development. The objects of knowledge, which are constituted via different schematizing operations, are qualitatively different in addition to possible quantitative changes.

Now it may be argued that these constructed objects of knowledge will always be intuited in spatial, temporal, numerical and/or causal form. These categorical forms of intuition provide the continuity of cognitive organization even though it is constantly changing in the course of developmental growth.

Nevertheless, the various schematizing operations which emerge at different stages insure the discontinuity of cognitive development. For example, sensori-motor means result in different organizations of space than do formal operations. The forms of spatial knowledge, as a consequence of sensori-motor operations, are the resultants of actual manipulations by the organism within his environment. In this sense the organization of space is relatively egocentric, i.e., the intuition of space is not differentiated from the actions involved in its apprehension. It is grasped in an immediate, external fashion such that the spatial group achieved is that described by the action itself. Consequently, it will be a buccal space, a prehensile space, a visual space, etc. These spatial schemata are not even coordinated with each other in the earliest substages of sensori-motor activity (cf. Piaget, Construction of Reality in the Child). They are radically discontinuous from those constituted in the highest stage of cognitive development. The spatial knowledge is differentiated from the operations involved and is the result of internal operations. Consequently, it becomes feasible to construct possible spatial systems in addition to those which are actually intuited, e.g., the conception that the earth revolves around the sun in addition to the immediate external intuition of the sun revolving around the earth.

I believe that this formulation of functional (sensori-motor actions through formal operational) discontinuity and organizational (spatial, temporal, etc.) continuity consistently complements the picture of functional (assimilatory: accommodatory) continuity and organizational (cognitive) discontinuity presented by Professor Piaget in his Psychology of Intelligence. It raises the major problem, however, of the processes whereby external forms of knowledge become interiorized as schemata. We shall return to this issue after briefly making certain distinctions with respect to the process of expressing and communicating knowledge. This should permit a fuller understanding of the ramifications of the problem of interiorizing and exteriorizing knowledge.

In order to communicate knowledge, whether to oneself as in inner speech or to others as in external speech, it is necessary to make reference to some object(s) of cognition. This requires the embodiment of the referent in some vehicle of expression. The process of depicting referents is representation. Now, the stages of schematizing operations involved in forming symbolic representations of knowledge are not well delineated. Much ontogenetic research analogous to that provided by Piaget on the development of knowledge is required. However, it is clear that the earliest representations are bodily gestures. Professor Piaget himself has provided us with many examples of postural-gestural representation by pre-verbal children in Play, Dreams and Imitation. To cite but one example:

> At 1; 4(0) L. tried to get a watch chain out of a matchbox when the box was not more than an eighth of an inch open. She gazed at the box with great attention, then opened and closed her mouth several times in succession, at first only slightly and then wider and wider. It is clear that the child, in her effort to picture to herself the means of enlarging the opening, was using as "signifier" her own mouth, with the movements of which she was familiar tactually and kinaesthetically as well as by analogy with the visual image of the mouths of others. (p. 65)

As can be seen from this example, the symbolizing operation involves making reference to a cognitive problem, i.e., getting the chain out of the box, by gesturally representing it. The gesture schematically depicts the dynamics of the situation. There are at least two components to this schematic depiction, namely, pretending and imitating the dynamics of opening a box.

It is clear that the symbol, in this instance, is relatively little differentiated from the object of knowledge which it represents. It is a relatively natural form of expression since it closely mimics the object of reference. This is also characteristic of those vocal-gestural representations usually referred to as onomatopoesis.

At the opposite end of the developmental continuum the forms of schematizing expression are relatively conventional and artificial. The symbol is well differentiated from the referent which it represents. The name 'cow' is arbitrarily assigned to a schema of knowledge. This makes it possible for me to communicate with you now about that object of our knowledge, cow, without any actual exemplar being present.

There must, of course, be transitional stages between these extremes. For a more comprehensive treatment I refer you to a recent work by Werner and Kaplan, Symbol Formation. I might just suggest that these transitional stages are partially natural and partially conventional. For example, when the child yells "mama" much of the meaning is represented by the vocal-gestural qualities of excitement. This is also an important quality, but to a less degree, of adult representation. Gestural expression may serve as a conjunction or substitutive function in adult verbal-linguistic communication.

Communication--exteriorizing and interiorizing knowledge--must be looked at not only from the viewpoint of the organism's representational activity. It must also be looked at from the viewpoint of the community. The knowledge of a community is its scientific, ethico-religious, aesthetic, etc., cognitive systems. This knowledge is symbolized in its mythical, linguistic, mathematical, etc., codes (cf. Cassirer, E. The Philosophy of Symbolic Forms). The problem of communication, then, becomes how the community's and the organism's symbolic codes match up. It cannot be emphasized too strongly that the problem is twofold. It is both a question of how the organism interiorizes knowledge, and how cognition is exteriorized by the organism and the community.

This is particularly interesting if we maintain, and I for one would, with Professor Piaget that the spatial, temporal, etc., categories of knowledge are already being constructed by pre-verbal, sensori-motor operations. (One might note that Professor Piaget has reserved the title of The Construction of Reality in the Child for his study on the sensori-motor bases of cognition.) Then it is necessary to argue that both the basic forms and functions of cognition are interior as well as exterior in the first stages of development. In this respect sensori-motor actions are particularly suited to the simultaneous role of interiorizing and exteriorizing forms and operations of knowledge. Because of their bodily yet graphic nature they are little differentiated from the internal organization of knowledge and the external environment.

We may now directly face the question of what is becoming interiorized and what is becoming exteriorized in the course of development? While the forms of knowledge are progressively becoming interiorized schemata, the forms of expression are increasingly becoming exteriorized symbols. It is this dual process which insures progressive communication. After all, if knowledge were merely interiorized how could any exterior correspondence, and consequently comprehension, occur between communicants. Yet we know that the course of development is characterized by progressive understanding between communicants.

It is, then, the exterior means of expression which facilitate increasing communicative correspondence between individuals whose knowledge is, at the same time, becoming progressively interiorized. Progressive development is characterized by (1) the increasing differentiation of these exterior forms of expression from the interior forms of knowledge, yet (2) their increasing integration by the establishment of arbitrary representational relationships rather than the fused relationships (as exemplified by gestural representation, word realism, etc.) which obtain in the early stages. It is this process of differentiation and integration between interior and exterior forms within the cognitive organization of individuals which is the necessary condition for correspondence between the exterior expressions of different individuals. That is, it is the condition whereby individuals may employ exterior forms to communicate their interior knowledge and achieve increasing understanding.

I should like to turn briefly to another issue with respect to the development of cognition. When one characterizes development as progressive it becomes necessary to speak about an organizing force. I believe one may use the analogy of embryogenesis in speaking of an organizer which serves to direct the course of developmental organization (cf. Ludwig von Bertalanffy, Modern Theories of Development). I have the distinct impression from Professor Piaget's works that the end stage to which development is directed is that of perfect equilibration. This stage is characterized by formal operations. It involves operations upon operations and is consequently the highest possible stage of cognitive activity: dynamic equilibrium has been reached. The theoretical conception of cognitive development, then, is that of a closed system.

If development is truly a closed system, with formal operations as the last stage, then what happens in development when the last stage is achieved (at about 15 years of age, according to Piaget)? What happens to cognitive development--is that the end? I believe that the initial answer to this problem must come from a characterization of development which goes beyond the formulation of analogous functions at different stages. Although Professor Piaget has described cognitive development in terms of functionally analogous intellectual operations, I do not believe that he would deny that other relationships between these operations may obtain which further characterize development.

I would suggest that in order to conceive of cognitive development as an open rather than a closed system, it is necessary to speak of other relationships between cognitive operations. This should permit the theoretical conception of stages beyond formal operations. For example, one might have to consider exclusiveness, that is, functionally independent operations: when one achieves a new set of operations, in the course of development, the earlier ones are no longer available. More interesting, however, would be a consideration of subsumption or the hierarchization of operations which emerge at different stages. This would mean the integration of the earlier, more rudimentary operations, by the later more sophisticated operations, such as formal operations. The resultant cognitive organization may be radically different and require the emergence of new cognitive operations. This theoretical issue takes on practical significance if we extend our consideration of curriculum development to higher education, at the undergraduate, graduate and post-graduate levels.

Finally, I should like to raise a major problem which has been totally ignored at this conference, namely, the relationship of person-emotional development to that of cognitive development. Let us briefly consider some of the genetic relationships between the organization of affect and intellect which are not typically dealt with. The organization of personality is largely a matter of identification. It is similar to the problem of the identification of any other object of knowledge in the course of development. In that sense one may draw very interesting genetic parallels for longitudinal study. This would involve the investigation of the development of permanence, conservation, etc. of personal identity in the course of the life cycle (cf. Erik. H. Erikson, Identity and the Life Cycle, Psychol. Issues, 1959, 1, 1-171). To put it plainly, we have yet to study the mechanisms of integration which insure developmental coherence of identity (e.g., that I am the same person now as when I was a child even though I have changed). On the other hand, we still have much to learn about the disintegration of identity in pathology, e.g., in dissociation, amnesia, etc.

There are also some striking differences between the operations involved in the formation of personal identity and that of other objects of cognition. In conceptualizing the organization of objects of knowledge, one recognizes that in the course of development the individual gives different cognitive status to objects (cf. V. Aldrich, Philosophy of Art). In particular, the self takes on the cognitive status of a relatively subjective (i.e., internal, psychological, spiritual) object; while other things are made into relatively objective (i.e., external, physical, material,) objects of knowledge. This is why, for example, scientists come to distrust their personal assessment of phenomena and place so much trust in "objective" analysis.

Professor Piaget's distinction between efficacy and phenomenalism is particularly relevant in this regard (cf. Piaget, The Child's Conception of Physical Causality). These are the two basic causal relationships which are formed. In the sensori-motor stage of development no differentiation is made between efficacious and phenomenalistic relationships, just as no distinction is made between objects as subjective or objective. With development, efficacious and phenomenalistic relationships progressively differentiate. Efficacy becomes the intentional mode and phenomenalism the physical-causal mode. The cognitive status of subjectivity is given to intentionality--the inner state or reason for doing something (cf. Peters, The Concept of Motivation). If for example, I make a noise by hitting the table, then the cause of that noise may be asked. If we mean by this what is the reason for the occurrence of the noise we are asking a question of intention. That is, we are asking about the purpose for making the noise. On the other hand, if we are asking how the noise happened, then we are concerned with the physical relationships between objects which produce noise. The cognitive status of objectivity is given to the establishment of such physical-causal, external relationships.

At this point I should merely like to add that my comments have been directed towards some of the implications of Professor Piaget's powerful theoretical-empirical model of cognitive development for curriculum development. It is with this purpose in mind that I have taken this occasion to raise some problems. I hope they will serve to stimulate consideration of the relationship of communication and personal development to cognitive development.

DEVELOPMENT AND ASSESSMENT OF COGNITIVE STRUCTURES

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Approaches to the study of cognitive development and its assessment at the Institute of Child Development, University of Minnesota are presented in this paper by Charlesworth. Using Piaget's theory of cognitive development as a base, some intriguing experimentation with the "surprise response" as an indicator of cognitive developmental level are reported. Charlesworth also speculates about teachers' use of this approach to facilitate cognitive development.

Piagetian-type research in cognition presently being conducted at the Institute of Child Development is only indirectly related to concrete application in the field of curriculum building. However, I hope to mention just briefly at the end of this report a few ways in which the type of research we are doing may be helpful in alerting the teacher to some ways of improving or accelerating the educational process.

Our main interests at the Institute are directed toward isolating and controlling specific variables that are both involved in the assessment of cognitive structures as well as in their development. In the area of test behavior, for example, a study by Richard Dubanoski on egocentric perception (the subject is asked to interpret the nature of the stimulus when it is presented tactually on various parts of the head) is aimed at determining whether performance on the task is influenced by whether the subject is allowed to describe the stimulus spontaneously, as he himself sees it, or is instructed to describe the stimulus as the experimenter sees it. The problem of whether non-verbal tests of conservation of substances are more sensitive in ascertaining the level of cognitive development involving conservation than verbal tests which may discriminate against lower-class children with limited verbal experience is being attacked by Herbert Ginsburg. Ginsburg is also interested in determining the extent to which feedback concerning the correctness of the subject's response significantly influences test performance. Robert Klein, another graduate student at the Institute, is conducting research on the nature of perceptual strategies that are used when the child is faced with Piagetian-type conservation or transitivity problems where immediate perceptions are frequently misleading. Klein is also making detailed examinations of haptic investigation as contrasted to visually controlled orienting responses. I should mention here parenthetically, that much of this research has led us to spend a lot of time on developing apparatus and techniques for making reliable and meaningful measurements of the child's perceptual behavior. We think that once good measures of perceptual behavior are developed, we will be able to get to the mechanisms that influence test behavior itself. This we hope will be one big step toward learning more about the cognitive structures themselves.

I would like to discuss now my own research and I am going to do so in more detail than those just mentioned. My excuse for this apparent egoism is that I know much more about this research and because of this I see its relevance for the topic of this conference.

The project I am working on is divided into two parts. One part has to do with using the surprise response as an indicator of level of cognitive development; the other part involves determining whether the surprise response has any motivational properties that influence the drive level of curiosity behavior. I will begin with the former since historically it was the first problem I dealt with, although the second part on motivation has taken up most of my time recently.

The way surprise fits into cognitive development as viewed by Piaget is as follows. As we all know, Piaget views cognitive development as gradual acquisition of cognitive structures that mediate between stimuli and responses such that the latter become increasingly more adaptive and appropriate with age. Many of these structures develop as a function of recurring regularities among environmental events. For example, the average child has many highly predictable everyday experiences--he lets go of an object and it falls to the floor; he turns an object 180 degrees and the points on it that were close to him are now farther from him, and those that were farther are closer, and so on.

Two unemphasized aspects of the structure that mediate such events are: (1) such structures provide the individual with reliable expectations or anticipations of outcomes of events, and (2) they sensitize him to deviations from regularity. If an expectation is confirmed, the subject assimilates the event or object to him by employing the cognitive or behavioral operations that he has customarily employed in the past. If the expectancy is not confirmed (that is, if there is a deviation from what normally occurs), the subject usually responds with surprise or startle, and if there is no strong fear response, he proceeds in most probability to inspect the surprising event or object. This inspection may be any form of curiosity behavior--orienting the sense receptors to the object, touching the object with the hands, or asking himself or someone else questions about it. In any case, as I see it, the exposure to the unexpected is extremely important in cognitive development since it enforces accommodation and thus increases the chances of subsequent modification of existing cognitive structures. It is these modifications that most likely increase the latitude of the subject's adaptive capacities.

Returning now to the surprise phenomenon itself, it seems to me that the fact that some children are surprised at some events and not at others may be very important in determining what their level of cognitive development is at a particular point in their growth. Conventional assessment methods so far depend heavily upon either the child's verbal responses (as we find in the "clinical method" espoused by Piaget) or upon his non-verbal behavior, as we see it in such studies as Braine's. Both methods have their weaknesses and strengths. Both, superficially at least, appear to measure the same thing and at the same time, as Flavell has mentioned in his book on Piaget. Both actually may be measuring different aspects of cognitive development as well.

The research I have started and hope to continue is aimed at devising a third approach to assessment based on the notion that the introduction of unexpected deviations in what are normally regularly recurring events will produce surprise responses that are sensitive indicators of whether the individual has a particular cognitive structure or not. Thus, instead of viewing behavior on Piaget-type tasks in terms of relatively complex patterns of learned verbal and instrumental responses, the strategy is to examine task behavior predominantly in terms of involuntary emotional (autonomic) responses (such as GSR changes) and expressive responses (changes in facial expression, spontaneous verbal and vocal responses, and delays in simple instrumental non-task oriented behavior). These behaviors would be elicited in response to experimentally contrived surprising events, events that would be made to appear as dramatic violations of certain laws governing physical reality. For example, if a child has the necessary concept(s) for conservation of substance, he ought to show discriminably different responses to an apparent violation of conservation than to an instance where conservation was preserved. If a child does not have the necessary concept, his responses to both situations would be essentially similar.

In one of the first experiments aimed at testing the hypothesis of different responses to apparent deviations from reality according to developmental level, the experimenter employed a situation in which the "law" that marbles and similar objects are not changed in color or number by merely shaking them in a container was apparently violated. The experimenter (E) used a "trick" container especially constructed for the purpose. The container had two spouts into which marbles could be inserted and from which they could be poured after the container was shaken. Marbles inserted into the input spout would roll into the container in view of a subject (S) and then out of the container through a hidden aperture beyond S's view to a receiving pad behind the screen where E was located. A delivery tube known only to E led into the container's output spout, thus allowing E to control the number and color of marbles that appeared to be poured directly from the container. From S's viewpoint the law of conservation of substance was apparently violated whenever the output marbles differed in color and number from the input marbles.

S's task was to put a specified set of colored marbles into the container, leaving a similar set behind in a trough as a memory aid, watch the container as E shook it automatically, and then respond to the color of the first marble as it emerged from the output spout by pulling a lever designated with the same color. A panel containing three levers, each designated with a color of a marble, and each connected to two timers was placed before S. When S pulled the lever corresponding to the color of the first marble that was poured from the container, the first timer recorded the response latency, i.e., the period between the time the first marble appeared in view and the time it took S to begin pulling the appropriate lever. The second timer recorded the time it took S to pull the lever the whole length of the lever track. Thus the time it took S to respond to the event of the appearance of the first marble was considered as a dependent variable as well as the time it took him to make the full response of pulling the lever the complete length of the track.

Two experimental groups were observed in this experiment, one group for which output marbles always equalled in color input marbles (No Surprise) and one in which output marbles never equalled input marbles (Surprise). All Ss were between four and eight years of age and hence were mature enough to have the concept of conservation of substance. It was hypothesized that Ss in the latter group would be surprised upon observing that output did not equal input, and hence would take longer to react than Ss in the former group. Results indicated that, in addition to showing more evidence of surprise, as observed in facial, verbal, and erroneous reaching responses, Ss in the Surprise Group showed longer latencies in responding than Ss in the No Surprise Group. One conclusion drawn from this study was that latency of response, as measured by the lever-pulling device, could be used in subsequent studies as a potential indicator of the presence or absence of certain cognitive structures which would predispose an individual to expect one event rather than another.

In another experiment reaction time to a contrived unexpected event which apparently violated a physical law was used to determine the child's comprehension of the effects of a 180-degree rotation on the linear order of objects. Subjects were shown a rotating wooden bar into which three different-colored pegs could be inserted horizontally. A panel containing three levers corresponding in color to the three pegs was placed before the subject. The experimenter inserted the pegs in the bar, covered them, and rotated the bar 180 degrees. The subject's task was to watch one side of the covered bar, predict the outcome of the rotation, and, as soon as the cover was removed, pull the lever corresponding in color to the color of the peg on the side indicated. For subjects in the "Real" Rotation Group the 180-degree rotation inverted the order of the pegs, whereas for "Trick" Rotation subjects the rotation was contrived to produce the original order of the objects. A Piagetian-type test of comprehension of rotation was administered afterwards as a criterion measure.

The results indicated that: (a) reaction times to pulling the correct lever under "Trick" conditions were significantly longer than under "Real" conditions, and (b) there were small but significant correlations obtained between reaction times and performance on the criterion measure. It was concluded that measuring delay in reaction time, as one of many so-called effects of surprise, to a contrived unexpected event could be an effective way of determining the developmental level of Piagetian-type cognitive structures.

As a result of these studies, plans have been made for working with the GSR and other involuntary or expressive responses in an attempt to employ them as possible diagnostic tools along with the standard assessment methods. It is hoped that some or all of the various surprise responses may be sensitive indicators of the presence of structures in their incipient stages. Furthermore, using surprise may be a possible way of testing to see if the subject has a pseudo-concept or a real one. It is hoped that careful examination of surprise responses, i.e., (the dynamic aspect of cognition) to apparent violations of laws governing reality or to apparent contradictions in what the child assumes to be true, will shed more light on the process of cognitive development itself.

The second aspect of surprise I would like to mention has to do with its motivational properties. Piaget has put strong emphasis on the role the child's actions play in the development of cognitive structures. After acknowledging that the act is the important thing, it seems to me that the next big problem is how the act gets started. In other words, what motivates all those actions during infancy and childhood that ultimately contribute to the formation of such solid, law-abiding cognitive structures which appear in adolescence.

The reinforcing effects (and I suppose we could say motivational effects) of novelty are well known. Piaget, himself, noticed this a long time ago in Laurent's rattle-banging tendencies. The reinforcement of such primitive curiosity behaviors as Laurent's assiduous attempts to reproduce a particularly pleasant, but unfamiliar stimulus are obviously important in the strengthening and consolidating of newly acquired schemata. Thus, it appears that the reinforcing qualities of certain stimuli clearly play an important role in the process of assimilation, a fact which Piaget emphasized in his book Play, Dreams, and Imitation in Childhood when he said that "interest is merely the affective aspect of assimilation". In view of this I would like to entertain the idea based on some studies recently completed, that surprise be considered the affective aspect of accommodation. I say this for various reasons. When we observe a child in an unexpected problematic situation, a few things are apparent. First he appears to have the good intention of assimilating (almost automatically) the situation to whatever he wishes. Then he is blocked by the fact that things turn out differently than he expected. In other words, the attempt to assimilate has failed. However, such a failure could be a signal for accommodation, in the form of curiosity behavior, to begin. The surprise as a response-producing stimulus may act both as this signal as well as an instigator of the curiosity response. Unlike novel stimuli that serve as reinforcements, surprise stimuli always occur before rather than after the curiosity behavior, hence the use of the term "instigator" rather than reinforcer. I cannot go into theoretical or terminological intricacies at this point regarding differences between the two. However, I assumed there is a significant difference between the novel and surprise characteristics of stimuli and their effects on curiosity behavior. This assumption led me to an experiment which I would like briefly to report.

The apparatus and the procedure described earlier in the experiment using marbles in a container were used here as well. The hypothesis tested was whether subjects who were surprised by the fact that the output marbles always differed from the input marbles stayed in the game longer than: (a) subjects for whom output always equaled input but where the marbles were different from trial to trial (hence novelty), (b) subjects for whom output always equaled input and the same marbles were used for each trial (hence boredom), and (c) subjects for whom the input marbles were never visible, thus they never had precise expectancies, but the output was always visible and changed from trial to trial (hence novelty). The results indicated that the subjects who were supposed to be surprised by the apparent violation of the law governing conservation of substance were surprised as far as the observers were concerned. The subjects gave significantly more behavioral indications of surprise (mostly changes in facial response) than those who were not supposed to be surprised, and more importantly they stayed in the game, (i.e., showed greater resistance to satiation) significantly longer than subjects in the other groups. These findings were interpreted as supporting the notion that surprise constitutes an important part of the motivational mechanism that is responsible for the expansion of cognitive structures through the incorporation of novel stimuli; or, in other words, surprise acts to motivate the subject to keep the novel unfamiliar information in touch with his sense receptors long enough for new learning to take place.

Another study on infant peek-a-boo behavior suggests that when the person peeking at the infant varies the loci of his peeks at random the infant persists in playing the game longer than when all the peeks are made from the same place. As in the experiment just mentioned, this persistence was interpreted as a result of the increment in drive level produced by the fact that expectations concerning peeks in the random situation were not always confirmed, hence the subject was surprised more often than in the other situation.

Whether I really have something here as far as the motivational aspects of surprise are concerned has still to be tested out more thoroughly. Other explanations, especially those offered by modern behavior theory, may be more parsimonious. However, I doubt this. Whatever the final explanation of the effect of disparity from an expectation on motivating behavior is, one thing is pretty certain. An unexpected event, whether it involves a gross violation of a physical law or a disparity from a predictable series of learned events, has a critical effect on the subject's curiosity behavior. For this reason focusing on unexpected and expected events appears to me to be important in the educational process. Creating environments in which expectancies can be established and confirmed or unconfirmed by new events seems to me to be an important part of the teacher's task.

Dr. Suchman will tell you of the importance of creating situations for the child which will elicit inquiry, i.e., the setting up of a series of events which will arouse dissonance, in Festinger's terms, that can only be reduced through a series of accommodative steps that make up the inquiry process. The "torpedoing" of misleading ideas, discussed by Dr. Davis as a critical tactic used in the Madison Project, fits into this whole scheme very nicely. We either allow the child to construct correct but incomplete hypotheses or expectations about events before presenting him with a new single non-confirming instance which challenges his hypothesis to the extent that he seeks to expand it, or we allow him to pursue misleading ideas before presenting him with a carefully selected fact or event that will suddenly contradict and hopefully rectify them.

The equilibration process which Piaget so aptly clarified for us embodies some of these notions. The child adopts certain strategies which, though limited in their coverage of the problem, initially lead to success, but then fail because of some environmentally-induced change in the problem situation. A shift to another strategy which also produces a temporary quasi-equilibrium occurs, but it too turns out to be inadequate. And another strategy, based on, but not necessarily derived from the first two, gradually emerges as a result of the uncertain oscillation between them.

As some French studies (e.g. Greco's rotation study) have shown, the greater degree of transfer from training to test behavior was achieved when all of the subject's expectations concerning outcomes of certain events were not always confirmed. In fact, the training situations were undoubtedly taxing and frustrating at times. It is possible that the surprise induced by such deviations from the expected served both to arouse the subject to the real nature of the problem (i.e. increase his overall level of vigilance) as well as to instigate him to examine, through some form of curiosity behavior, aspects of the situation which he initially neglected. The sudden deviation from the expected, as observed in the now classic von Restorff effect, not only alerts the subject, but also appears to improve his capacity to retain the newly-discovered information. This retention subsequently contributes to the ultimate modification of existing cognitive structures.

Under natural conditions where structural changes develop spontaneously, surprises occur as often as the environment creates expectancies and violates them. It seems to me, then, that one task of the teacher would be to accelerate this process by judiciously choosing and applying both kinds of events in a learning situation. This requires that the teacher be aware of what information the child has at the moment, i.e. what his cognitive predisposition towards the subject matter is. This may be a strenuous requirement, however, I would not be surprised if good teachers do just this most of the time anyway. Whether all good teachers are aware of the effects of surprise on eliciting curiosity behavior and apparently improving retention of material is another thing. It is here where research may make some contribution. However, as is clear from the paucity of reportable experiments, research in this area is really just beginning. Much of what we can project into the realm of educational application is still conjectural at best. But beginnings must be made somewhere, and this conference can serve as a stimulus to see that they are made.

INTERNAL NECESSITY AND CONTRADICTION IN CHILDREN'S THINKING

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Smedslund presents an hypothesis about logical (internal) necessity and contradiction as empirical contingencies in the determination of children's intellectual and personal development. The difference is distinguished between Piaget's concept of equilibration (as "the accord of thought with itself") and learning (as "the accord of thought with things"). Citing the similarity of the concept of equilibration to Festinger's cognitive dissonance theory, Smedslund holds that the direction of the changes in children's thinking is not determined by external reinforcement.

I would like to present very briefly an hypothesis about certain aspects of cognitive development. There will be no time for a detailed review of the evidence relating to this hypothesis.

There appears to exist a process of change, important in child development and in adult life as well, which does not fall under the conventional headings of maturation and learning. It cannot be labelled maturation, since it is initiated by experience. On the other hand, it cannot be considered as learning, since it is not guided by information from outside the subject. This process, initiated, but not guided, by experience, has been labelled equilibration by Professor Piaget. The two first mentioned processes will be characterized briefly, and then the process of equilibration will be analyzed more closely.

Learned behavior is stabilized by exact or probabilistic environmental contingencies. Nonsense syllable B is expected to follow nonsense syllable A, because this has been consistently the case. A right turn at a certain point in a maze is repeated because it has led to the goal more consistently than a left turn. Thirsty children turn taps, because they have experienced a considerable correlation between the turning of taps and the emergence of water. Learned behaviors are extinguished when the supporting contingencies disappear. Changes in the syllable list, the maze, and the correlation between taps and water normally lead to changes in the learned behavior.

Instances of psychologically relevant maturation are not so easy to find. However, it seems highly probable that children's capacity for information processing increases over age, as witnessed by the increases in memory span, attention span, and the complexity of their inferences. If it could be demonstrated that this increment in capacity cannot be influenced by the type of experience a child is subjected to, one would have a clear case of maturation, in the sense of the term used here.

As an example of a concept assumed to be acquired primarily by equilibration, I will use conservation of quantity. Conservation means that the quantity in a given object is conceived of as invariant over deformations and deplacements of the object. The process of equilibration has been studied in several experiments with this concept. In one of them, the subjects were five-year-old children who believed that the quantity in a given object changed with changes in its shape, and who frequently justified this by saying "I can see it". After a series of questions with many different objects, and involving additions and subtractions as well as deformations, many of the children suddenly stated that quantity remains invariant over deformations, "because nothing has been added and nothing has been taken away". This new judgment went against the actual perceptual impression, and was not supported by any cues from the experimenter. Although the acquisition of conservation apparently was not directly guided by the subject's experiences, it was, definitely, initiated by these experiences, since control groups of subjects who were not given any questions, showed little or no improvement. It is of further interest that the source of stabilization of the concept of conservation apparently lies in a realization of it's logical necessity. This is directly revealed in the subject's usage of expressions like "it must be the same", "it has to be the same", etc. It is also reflected in the exceptional resistance to extinction of the concept.

In an experiment on conservation of weight, subjects who already had conservation were confronted with some instances of apparent non-conservation. This frequently did not lead to a rejection of the concept, but only to auxiliary explanations like "the balance is not working", "we must have lost something on the floor", "you added something", etc. Apparently, the concept of conservation is supported by the argument "nothing has been added and nothing has been taken away" to the extent that it becomes completely independent of empirical contingencies.

Other notions, such as transitivity, have completely analogous properties. If an older child or an adult observes that stick A is longer than stick B, and that stick B is longer than stick C, he will invariably infer that stick A is longer than stick C. Furthermore, if he is shown that stick C is longer than stick A, he will infer that at least one of the sticks must have changed its length during the measurement period. Transitivity is not given up since it is, in a certain sense, logically necessary.

In addition to learning about the empirical contingencies in their world, children gradually discover logical necessities and eliminate latent contradictions in their conceptions. The theory of Festinger and others about cognitive dissonance is closely related to the notion of equilibration. The changes are initiated by dissonant experiences, but the direction of the changes is not determined by external reinforcements.

Piaget has very aptly characterized the difference between learning and equilibration as a difference between "the accord of thought with things" and "the accord of thought with itself". The former has been the province of learning theory, but the latter has been pretty much neglected up to now. Educators should seriously consider the difference between these two processes. One may be said to learn the history of ancient Egypt, since this is a series of empirical contingencies. However, it is probably a serious mistake to believe that the general principles that are valid for the preceding example can be applied to the acquisition of geometry which is a system of closely knit logical structures. One does not learn mathematics.

Conclusion: Internal necessity and contradiction are equally important as empirical contingencies in the determination of children's intellectual and personal development.

DEVELOPMENT AND MEASUREMENT

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Wohlwill calls for longitudinal studies and a sequential analysis to help solve the mystery of cognitive development. He holds that as a child develops, his perceptual set in approaching problems is supplanted by a different set which has to do more with symbolic operations relating to concepts. The development of this new set is discussed together with the role of measurement in the developmental process. Implications are drawn for providing general types of early experiences to facilitate cognitive development.

What I would like to talk about briefly concerns some general thoughts relating to the discussion inspired by Professor Piaget's remarks, and to the controversy that followed it. This will bring us to a topic brought up by Professor Piaget, the topic of measurement, which I feel is of general interest with respect to some of the concepts that Piaget has dealt with.

There was some feeling expressed in the discussion that we didn't have to invoke any mystical force to account for the development that one observes in the acquisition of conservation and certain other kinds of problems. Piaget rejoined that he did not feel any particular mysticism involved here and that the phenomena could be accounted for consistently in terms of his model. I certainly wouldn't want to argue here for a position of mysticism, but I do want to suggest that there is a mystery here nevertheless. (I don't think you have to be a mystic to enjoy a mystery, and I do enjoy this one.) The mystery for me has to do with the nature of the change that takes place in the child's mode of reasoning. Let us consider a child, say a five-year-old child, who is responding in a perfectly self-assured manner in a nonconservation sense; that is, he feels that once we stretch out the ball of clay, then there is more clay. This same child, maybe a year later, will make a complete turnabout and declare that obviously you haven't changed anything, it is still the same amount of clay.

The forcefulness of this point is somewhat diluted, I think, if you simply look at one group of children at one age as opposed to another group at an older age and simply compare these two groups of children. Then it looks a little like just two different breeds of cats, and you tend to ignore the fact that one child actually changes to become a member of the other group. I might simply refer you, in this connection, to some films that I have always felt are among the most convincing and dramatic illustrations of the reality of the phenomenon which takes place in the area of conservation, for instance. These films were made by Dr. Inhelder at Geneva showing a single child at successively different levels of reasoning with respect to the conservation problem, spanning about a period of a year or a year and a half at the most. (In part this is just a plug that I would like to make for more intensive longitudinal analysis of this sort to trace the change in the nature of the reasoning processes of a particular child.) These are longitudinal studies that don't have to encompass generations, with all the difficult problems that arise in such projects; they can be quite limited and self-contained and easy to manage. But I do think we stand to gain a good deal by looking at what actually goes on during the period in which this change must take place.

Meanwhile, although we don't have a good sequential analysis of this problem as yet, I would still like to address myself to the general question, "Just what is it that's going on here? How can you account for this change in the reasoning process?" Let me simply state that I don't think, with respect to most problems of this type, that you can really account for it in terms of the acquisition of a specific response. The child typically does not have very much direct experience during such an early period in judging the relative weight of things while the shape is altered, for instance. This doesn't mean that I'm ruling out the role of the experience that the child may be exposed to in this period. I do think that experience has something to do with it, but it is not a matter of acquisition of specific responses. The question then arises, what kind of experience or what aspects of experience are important here, and in what manner does it act to effect this particular change?

Professor Piaget has given us a general answer as to how to approach this problem in his equilibration model. That is, he suggests that there are certain modes of response that tend to satisfy the child for a while, but later he will be led to explore other possibilities or be confronted with contradictions arising from his mode of reasoning that will compel him to move on to the following level. In general terms this is undoubtedly a useful way of looking at the matter, but it still leaves open a variety of specific alternatives as to the exact nature of the processes at work here. Or, if you ask the question, how one might manipulate experience in such a way as to induce the child to change his level of reasoning, the equilibrium model still allows for a variety of possible solutions to this question.

One particular approach is the one which Dr. Smedslund talked about, having to do with the notion of cognitive conflict. That is, you actually put the child in a bind, as it were, as the result of a particular preoperational type of reasoning. You confront him with inconsistencies in his judgment without giving him any answer as to the way out, and simply expose him to this presumably somewhat stressful situation - not necessarily stress in the negative sense, but one which impels him to move on, as it were. You get him to resolve this conflict by changing his mode of conceptual functioning. Dr. Smedslund has indeed succeeded in illustrating the possible role of this type of process in some of his experiments quite convincingly. But a question arises here as to the place of this kind of cognitive conflict in the normal process of cognitive development.

A former student of Piaget's, Hans Aebli, now at the Free University of Berlin, has actually gone one step further. Essentially following this position of Smedslund's, he has suggested that we should look for the locus of the cognitive change in the experimental situation itself. Outside of the experimental situation there is just a general diffuse maturation going on and if you actually get a child to change his mode of reasoning it is as a function of his exposure to questioning of the type that you normally find in a conservation study or the like. Now, for me at least, the problem with regard to this position--and I would be inclined to make the same argument against the generality of the answer that Dr. Smedslund has given us--is that if this were the case it would be just too bad for the 99.99 per cent of the children who never find their way into a Piaget-type experiment. How would they ever come to function in the way you expect? There must be something in the normal process of development that takes the place of this experience, or makes up for their lack of good fortune in this respect. In general it seems to me implausible to suppose that a child is normally exposed to that much cognitive dissonance, let's say in the kindergarten or first grade period during which these things seem to develop ''spontaneously.''

I don't really have a terribly good specific answer to propose to solve this mystery. However, I would like to suggest one alternative here, and that is that the child comes to develop a different attitude or a different type of set in responding to a conceptual problem. The preconservation child, the child at the age of intuitive thought, is responding mainly on the basis of particular perceptual cues which to him dominate the situation. Thus, if you stretch out the piece of clay, this leads him to assume a change in the weight of the piece, based on the obviously visible change in the shape or the length of the piece. In other words he is operating on the basis of a perceptual set in his handling of the concept of weight.

You could describe in similar terms the child's problem with respect to the conservation of number: if you stretch out the row of buttons, he is responding to this immediately visible increase in length. What seems to me to happen, then, is that a different kind of set emerges during this period, which has to do more with the symbolic operations that relate to that particular concept. In the case of number this would of course involve such operations as adding, subtracting, counting--although I think that has to be qualified, because simple rote counting does not seem to be very effective here. But given a particular quantity of objects, a child looks at number as something that has to do with adding pieces or taking pieces away. Similarly, in regard to the conservation of weight the notion would be that the amount of weight has to do not with the object's looks but with such things as comparing weight on a balance, for instance. Or the quantity of liquid has to do with measuring the relative amount of water through some kind of a measuring instrument. It seems to me the whole notion of measurement is essential to all of these kinds of phenomena. What I am suggesting, in other words, is that this different type of set in responding to these concepts supplants the earlier one, and that the perceptual approach is gradually sloughed off, as it were, as the child develops. He isn't aware that he is giving anything up; it simply becomes a kind of vestigial form of reasoning.

As you can see, at some point both of these tendencies may be in some sort of balance, since one is going down as the other one is going up. Presumably if you catch a child at the point when both of these tendencies are present to almost equal strength, then exposing them to a cognitive-conflict type of situation may be effective in getting him over the hump. But I don't think you have to argue that this is a necessary condition for the change; it will simply speed it up if you happen to catch him at that particular moment.

Well, now you might ask, "How does this new type of attitude or set develop?" Some might argue that this is a matter of learning experiences that a child ordinarily gets exposed to in our culture, through school, through the kinds of toys he has, etc. One point to be made first of all, however, is that you have a situation here where one type of response set supplants another. It is not simply the acquisition of a new response, in the sense that a child might learn about something that he did not know before. It is not the acquisition of facts or knowledge generally, but it is a matter of giving up one type of response, which is extinguished while another one is being developed. I think that when a learning interpretation is advanced, this has to be borne in mind.

Secondly, while undoubtedly experience in the general sense is quite important here, one has to look at the timing of these processes. I would argue that it is probably impossible to devise experiences that would develop this kind of a conceptual attitude while the child is at the height of the perceptual-dominance stage. I suspect that one of the factors involved here is the development of language and of other mediational processes, such as observing responses, in this transition period. I am not putting the stress on language as such. I think it is more of a correlational situation where the development of language serves as a symptom of the same process reflected in the changes in the development of the child's reasoning. These go hand in hand. In the same way it would probably be futile to try to teach a three-year-old child the use of words that relate to a set of concepts such as equilibrium, for instance. I am sure you could teach a child to use these words but they would have highly limited meaning. In other words, I think one has to look at the role of experience in relation to the level of the development of the child.

Finally, in a more positive sense, what type of experience is likely to be relevant with regard to these kinds of processes? The kind of conception I have suggested here would indicate that it should be an experience which gets the child involved with the conceptual aspects of the situation. This might consist of activities which involve adding things together, or measuring by comparing things quantitatively. More particularly, it seems to me that the experience ideally should have a built-in feedback possibility for the child. I believe that externally administered reinforcement, or information as to the correctness or incorrectness of the child's response is not going to be very fruitful. On the other hand, there is a variety of actions that the child can do which provide him with feedback in regard to the effect of his actions. A particularly good illustration of this point was contained in the example that Professor Piaget cited of the mathematician who discovered conservation by rearranging a group of stones and beads in order of size and counting them forwards and backwards. The process of counting itself in this particular situation provides built-in feedback, since one finds out by counting that the total number is always the same.

I would be somewhat reluctant to put too much stress on counting as such in relation to the conservation of number, however, in that some work that I have done in this area suggests very definite limits as to how far the child will go on the basis of simple counting. Let us suppose you put the child in a conservation situation where there are two equally-spaced rows of beads and he agrees that the two rows have the same number. Then you stretch one row out and you ask, "Who has more beads, you or I, or are they the same?" He may give a non-conservation answer, "You have more because you have stretched it out." Now I have had children in whom I had previously built up a definite set to respond to number (so you can reasonably assume that for them "more" had reference to "greater number"; they had gone through a long series of number responses). After these children gave such a non-conservation response, I had them count both of the rows. Occasionally you find a child who seems deliberately to make it come out wrong, in accordance with his hypothesis. He'll count one row, let's say to seven and so he'll count the other, "one, two, three, four, five, (skipping a bead) six--see, you have more!" Most of them won't be quite that smart, and they find that they have seven and you have seven. Then you repeat the question: "Well, who had more, you or I?" They still persist: "You have more, because it's longer." So, simply confronting himself with the equality of these rows isn't necessarily the answer here. The aspect of the previous example of Professor Piaget's that struck me at once was the fact that the child did engage in some action with the material. Perhaps this spontaneous action had something to do with the success of this particular case.

In any event I would say that getting children involved in manipulating the material in the conceptual sense, rearranging the objects, counting them and balancing them--this does strike me as a useful way of looking at what normally happens in the development of the kind of concepts which we have been discussing. The notion of measurement, as we have seen from Professor Piaget's paper, is, of course, itself subject to a very definite developmental process. But I think that if you work on that and follow it step by step, trying to develop the concepts and skills involved in that particular sequence by relevant types of experience, this would be likely to yield a good deal of transfer with regard to such notions as conservation, transitivity and other concrete-operation concepts.

In closing, let me say one word concerning the question of acceleration. I think, first of all, one might ask the question, why do we want to accelerate development? What is so desirable about getting a child who normally would acquire a certain kind of reasoning at six to show it at the kindergarten level, and continuing from there on, to find that you can perhaps cut two years off his normal schooling period? The net result of this is that you throw him into the labor force that many years earlier, and that creates an employment problem. Maybe we should work on the opposite premise and try to *extend* the curriculum for several years to ease up the employment situation. But, more seriously, I think you have to ask the question, what exactly are you doing when you do this? Is it possible that you are accelerating the process of cognitive development with respect to one particular concept at the expense of breadth or generality of learning or transfer to other later concepts? I can conceive of the possibility of considerably accelerating the child's appreciation of the conservation of weight, for instance. But it may be that the other things which normally would develop at the same time, such as notions about transitivity, would be left behind, as it were, and as a result you have a particular pattern of conceptual responses that may not be such a useful one.

I would throw out a tentative hypothesis here, to the effect that the more generalized the experience that a child gets at an earlier point is, the less specific teaching instruction will be necessary later. An implication of this is that if we do manipulate experience at these early levels, we should make provision for a variety of types of experiences, including perhaps some rather unstructured ones, so as to be sure that one is not depriving the child of learnings which he would normally pick up in a more incidental fashion.

To conclude, then, I would place the emphasis in the teaching of scientific and mathematical subjects to young children on a focused enrichment of their experience, aimed at generalization and transfer, rather than at acceleration per se. Get them actively involved in measuring the sizes, shapes, weights, temperatures, etc., of the objects around them, in many different and even novel ways; set them problems to solve and operations to perform, giving them an opportunity to apply their measurement skills and the concepts embodied in them. If the child is thus provided with a broad base of experience, assuring him of extensive practice in abstracting structural similarities and common principles from diverse material contents or specific tasks, this may surely be expected to influence the development of his cognitive skills in a very favorable sense.

LEARNING AND THINKING IN THE SCHOOL SITUATION

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Peel, a British educational psychologist, comments on the impact of Piaget's thinking on the English educational system in this paper. Speculations are offered concerning the implications of Piaget's theory for learning in history and geography. Peel concludes that the basic ideas in Piaget's approach render a helpful account of learning and thinking.

The position in Great Britain is slightly different from what it is here in the U.S.A. In the first place, most of the people who have studied Piaget's psychology have been educators as well as psychologists. Secondly, our contact with the teachers is different. We have been slower in forming curriculum study groups on the large scale, but now it is different as seen by the Nuffield Foundation's interest in the curriculum and by the Southampton mathematical study group. On the other hand, we may have much closer personal contact with our teachers, which is usually made through courses given by the local authorities in which they invite someone knowledgeable to lecture about the findings of research into children's thinking. Usually such a person will illustrate the findings and ideas by reference to school situations and then leave it to the teacher to relate the results and ideas to his classroom work.

In the comments which follow I shall begin with a few educational consequences of the Geneva researches and then follow with some ideas and inquiries following my own work at Birmingham.

The revisions suggested in the teaching of science in primary schools and those for teaching mathematics in the infant and the lower part of the elementary schools are not concerned with any desire to accelerate, but to give the appropriate teaching at the right stage in the belief that ultimately the understanding of science and mathematics will be bettered. This is very true of infant school mathematics where conservation experiments are quite well known and where teaching on their basis is becoming more evident. The use of the apparatus of Cuisenaire, Dienes, and Shaw is independent of the influence of Piaget, but all contribute to the same end of greater enlightenment gained from experience and manipulation.

The teaching of the beginnings of science in primary schools illustrates well how much we can learn from experiments on thinking. Nature study and weather study can be made the experiential basis for promoting the child's power to classify and cross-classify. Both aspects of the child's experiences mentioned earlier by Piaget, namely physical action on the material (collection and examining) and logical-mathematical action in the formation of classes (inclusions, exclusions and orderings, etc.), are developed.

But this is not enough. As we were told in the opening session, most of the basic concepts of science do not maturate in their invariant conserved form until the child is well beyond nine years of age. Thus weight is not conceived as something independent of shape and substance until nine or ten years and volume as cubic capacity until eleven or twelve years.

Thus, science education in primary schools should be based on experience leading to the formation of concepts. As this experience becomes more systematised the basic concepts of weight, volume, time, speed etc. are established. Then within the framework of these 'invariants', the child groups, systematises and selects his observations to lead to the induction of concepts and laws. The stage of taking the invariants for granted and seeing nature in their terms is concrete thinking. I would call it describer-thinking.

The last stage of the induction of laws and formation of further concepts constitutes a bridge in thought between description and explanation. This bridge is important in the development of science thinking in the junior and high school pupil. We may not have made our study of this bridge explicit enough, although it is implicit in Piaget's developmental system. Ideas of concept formation and attainment and generalisation and abstraction are all involved.

The extending of a concept was brought out in the example that Piaget gave us of the observer of a moving object. Once we consider the situation where the observer is also moving, the concept of absolute motion becomes that of relative motion. We see that the concept has become more general and to that extent has the potentiality of a more powerful explanatory tool. As I see it physics is primarily concerned with the general and not with the abstract. This is a major distinction between it and mathematics which is primarily concerned with abstraction. We see the increased generalisation of physical concepts in the study of motion. The normal sequence of study is of speed, velocity (compounding speed and direction), relative velocity (direction and magnitude), and the special theory of relativity, all of which are at the same level of abstraction but show a progression in generalisation. We have not examined this problem of concept generalisation sufficiently. The bridging operation by concepts seems very important everywhere, but particularly so in England where transition from primary to secondary education takes place at eleven years of age, just when concept formation is beginning to be most significant.

The formation of concepts as opposed to their attainment poses yet another problem at this stage of transition between describer and explainer thinking.

Most of our sensitive tests of concept formation are given to younger children. Where they are given to older groups they are bound to test a growing element of concept attainment, since by now the student has available the logical machinery of classifying and relation finding and most of the basic first-order concepts required for action and perception. But we should find out a little more about the way of concept formation in adolescence, particularly with material which does not lend itself easily to first-order conceptualisation. The use of verbal data can provide such conditions.

In mature scientific thinking I am sure what goes on is a mixture of concept formation and concept attainment. I may mention Mendel's discovery of the hereditary laws. Superficially this looks like concept formation, but in fact Mendel was an experienced horticulturist and gardener and had already half-formed notions about parent-offspring relations. Another instance can be seen in the deciphering of the Mycenaean script of Linear B. Now here we can be sure that mature science thinking involves both attainment and formation of concepts. An important question still remains unanswered. Is the concept formation of the adolescent different in quality from that of the child? It would seem that by the end of childhood he already has available the operations of adding and multiplying classes and the repertoire of many of the concepts required for ordinary action and perception. In order to achieve this command of concepts he has in early childhood had to discover both the experiential criteria which form the basis of the concept and the laws of class addition and multiplication.

In adolescence he will have the latter, but in any wholly novel situations he will have to find criteria anew. So it looks as if concept formation in adolescence and adult life differs from concept formation in childhood only in that the hierarchical and multiplicative structures of the logic of classes and relations are available. But new criteria of action (mental and physical) and perception may still have to be constructed at all ages.

It is interesting to speculate how the ideas put forward by Piaget and Inhelder in their Growth of Logical Thinking in connection with science and material situations may apply to the learning of history and geography. The data of history are not like those of science, consisting essentially of the intentions behind the actions of people in the past. The first bridge, therefore, the teacher of history has to cross is that between present and past. He accounts for the past by whatever knowledge he can use from the child's present experience and by whatever concrete historical material he has available. In this way he builds up the right historical data. This stage would correspond with what I have called describer-thinking. But there is more to history than this. Its course can be viewed as a series of equilibria and disequilibria between the acts and intentions of men. The mature student of history is sensitive to the fine interplays and balance in such situations as the events in 1939 leading up to the Second World War or in the events in England among the working classes leading up to the Reform Act of 1832. A more recent interplay of forces between men was seen in the recent situation in Cuba.

The balance of powers, physical or human, involves the two important principles of cancellation and compensation which form an essential part of Piaget's account of adolescent thinking. Some investigations carried out recently using short passages of history demonstrated that this sensitivity is, under present educational circumstances, a characteristic of mid-adolescence.

Geography also reveals the same balance between environmental and behavioural forces. Thus, wherever mankind has upset the balance of nature in his attempts to produce more food etc., the same interplay of cancelling, compensating, etc. can be revealed. When pupils are confronted with such situations as tests of thinking in geography, as we are doing at Birmingham, we have found again that co-ordinated judgments do not appear to be widespread until mid-adolescence.

It seems, in conclusion, that whatever school subject we are concerned with - science, mathematics, history or geography - and at whatever level we are concerned with it, something very near to the basic ideas put forward by Piaget, Inhelder and their co-workers, or ideas developing from them, seems essential for a helpful account of the pupil's growth of learning and thinking.

THE ILLINOIS STUDIES IN INQUIRY TRAINING

J. Richard Suchman

University of Illinois

Suchman describes the Illinois Studies in Inquiry Training Project at the University of Illinois. Three conditions facilitating inquiry in classroom settings are identified--a focus for attention, freedom, and a responsive environment. The elaboration of these conditions and the shift in motivation resulting from creating them are discussed. Examples of the inquiry training process are presented. A pilot study is reported wherein it was discovered that children who rated high on cognitive control, impulsivity, and autonomy were more effective inquirers than children who were low on any of these three factors.

We have been trying to develop inquiry skills in elementary school children. This began back in 1957 when we were disturbed by the findings of some studies. One of these found that 97 per cent of the questions asked in the classroom were asked by the teacher. Another one found that as children move from the first grade to the sixth grade, they become less empirical and based more hypotheses and tests of hypotheses on conclusions of authorities and less on their own empirical operations.

Over a period of years we have identified what seem to be necessary conditions for inquiry to occur in classroom settings, and we have tried to build a program that creates these conditions. The conditions are essentially these: first, we find that the children need some kind of focus for their attention, some kind of problem or stimulus, and preferably, although not necessarily, one that is discrepant to the schemata or conceptual systems of the child. In other words, one that cannot be readily assimilated.

Secondly, they need the condition of freedom. We have broken freedom down into two parts, one of which is a kind of external freedom, that is, physical freedom to reach out for data and information desired, and to pull it in at any rate in any sequence the child wishes. This is anti-programing in a sense. Internal freedom is something that follows as a consequence. We found when you give children the external freedom, for a time they are inhibited and don't avail themselves of it because they have been conditioned to follow the teacher's lead and conform. But eventually, as they explore and find that external freedom does exist they begin to build up what we call autonomy in their operations. They make decisions and try to satisfy their own cognitive needs by gathering the kinds of information they want. There is also the exercise of freedom in trying out ideas, which is the other part of the picture.

There are two kinds of scanning going on. There is the scanning of the field for data, and the scanning of the store of ideas for conceptual models. These comprise two parts of the inquiry cycle. A child takes in a percept and he tries to find a model he can use to assimilate it. Then, providing assimilation is not complete, he performs some action to generate new data. At the same time as he pulls in the new data, he is scanning for new models to try out on the data. He is trying to make a match between the data coming in and the models being tried out. At some point the match between the data and a model is made.

The third condition is what O.K. Moore calls the "responsive environment." The child needs to have an environment where, when he reaches out for data, he gets something. He doesn't come back with empty hands. These, then, are three conditions for inquiry: the focus, the freedom to operate, and the responsive environment. If we provide these conditions we find that children inquire at the elementary school age, and that inquiry will progress at a rate that is far in excess of what would happen if one didn't have these conditions. I'm not going to say they are necessary, but they are clearly conducive.

I would like to comment briefly on the motivation operating in this situation. One of the outcomes of creating these conditions is that you do get a shift in motivation. When you have a teacher programing the learning experiences of the children (making the decisions as to what happens next) and you have children following the lead of the teacher, a good deal of the motivation falls into what we call the social-ego category. The children are looking for rewards from the teacher and from the situation, extrinsic to the learning activity itself. When you go into the inquiry mode, you start with a problem and the children are free to go at it and build their constructs as they see fit. The motivation becomes more cognitive, and takes two forms. One is the motivation to close the gap, to make the match between what is perceived and what is known, the motivation of closure. But we found that beyond this, after the children have found a reasonable degree of closure, they continued to inquire, to pull in data and to process them. They were motivated, it seemed, by the act of inquiry itself. We were particularly curious about this.

The motivation seemed to have different flavors. One was a kind of pleasure in the sense of confidence a child gets in processing data even if he doesn't have any great problems bothering him. The child picks away at an old alarm clock and takes it apart and puts it back together, not because he is trying to build a grand theory of alarm clocks but because it is fun and because processing the kinds of data he is getting from these manipulations is very satisfying to him. He continues to do it without any real problems to prod him. There is also a sense of power and excitement in being able to do this. To borrow a phrase that J. McV. Hunt at Illinois uses, "we see in children a motivation inherent in information processing and action'' and it seems to be a growing kind of motivational force that after a while tends to supplant the motivation of closure. In the beginning it seems pretty important to give children problems that are discrepant in order to provide strong early interest. But after a while it becomes less necessary and children start structuring problems for themselves rather than having to be given one to start with.

The set-up we use for making children aware of the inquiry process is something we once termed Inquiry Training. (We have been sorry about the word ''training'' ever since.) We have produced a series of films starting with physics (we now have economics and biology also) which are designed as discrepant events. They pose episodes which the children cannot assimilate without accommodating, or at least analyzing the event itself until assimilation is possible. The film then is the focus and offers the initial motivation. Next, we provide the freedom by allowing the children to ask yes-and-no questions to gather their data. These are questions phrased to be answered by ''yes'' or ''no'', but the teacher may qualify the answers where necessary. The questions are not attempts to elicit explanations or theory from the teacher but are strictly for data gathering, e.g., ''Was the blade made of steel?''

One of our films is about a bi-metal blade. When it is heated it bends downward, and when it is inserted into a tank of water, it straightens out. The demonstrator turns it over and puts it back on the flame. This time it bends upward, and when placed in water it once more straightens out. To the children who don't know anything about a bi-metal blade, this is a discrepant event. They take it from there, using ''yes'' or ''no'' questions. They can't ask ''was it because.'' If they start getting into this kind of questioning we tell them it is their job to find explanations. ''See if you can construct a theory. If you have one, you ought to be able to test it experimentally.'' Their experiments too are conducted through ''yes'' and ''no'' questions. ''If we put the blade into a refrigerator would the same thing happen?'' Such a question is the equivalent of an empirical test of a hypothesized relationship. The responsive environment is created by the teacher who answers the questions. As the children ask questions they build little theories which they test themselves.

We are now doing a study of the transfer of the effects of Inquiry Training with physics films, to see what influence this has on the ability to inquire into economics and biology problems. This is being done as a controlled study, in which we are comparing children who had experiences with physics against those who hadn't and checking out the effects. So far, although the data are not all in, one thing is very clear: inquiry skills do transfer - not method per se, but a kind of attitude, a sense of self-confidence that the child has in his own ability to handle data and to build and test theories. The trained child is more willing to try out ideas after he has had this kind of experience. As far as transfer of method or approach is concerned, we don't know how much carries over. Such strategies are very hard to identify and to measure, so I am not so sure if we are going to see evidence of the transfer of methods.

We conducted a pilot study last summer with a group of about 14 children to investigate the effects of cognitive style on inquiry. We had about 49 variables dealing with cognitive style, such as schematesizing, leveling, and sharpening, field dependency, etc., in addition to data from the Primary Mental Abilities test. An intercorrelation matrix, including inquiry and other cognitive variables, yielded three correlation clusters suggesting three factors relevant to success in inquiry. One is the cognitive control dimension, the ability to handle and manipulate data. A second correlation cluster suggested the existence of an impulsivity factor, the capacity to leap beyond data to generate abstractions. Impulsivity leads to moving away from the data rather than the "zeroing in" on it. In the inquiry process the child has to shift back and forth from high cognitive control to impulsivity. If you never leave the data you will never construct theory. This ability is related to a third factor which we have identified as autonomy. If the child is high on cognitive control, impulsivity, and autonomy, we find him to be a more effective inquirer than a child who is low on any one of the three.

COMMENTS ON THE INRC GROUP

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In Piaget's theory cognitive behavior in some problem situations can be likened to a four-group--a mathematical group whose elements consist of four transformations. These four transformations are represented as follows: I (identity), N (negation), R (reciprocal), C (correlative). The INRC group has logical and physical "realizations," i.e., different systems which exemplify its properties. Piaget holds that the acquisition of the INRC structure characterizes the stage of formal operations in children's thinking. In the snail problem, referred to by Easley, a snail is placed on a board which rests on a table. The snail can move from left to right or right to left while the board is stationary. Likewise, the board can move in either direction while the snail is stationary. Finally, the snail and the board can move simultaneously in either direction. In the following paper Easley presents an analysis of the snail problem in terms of the INRC group.

It has been a matter of concern to me and several others as to how we can make application of Professor Piaget's theory, because application seems to require deduction from the theory of new consequences. If the theory is not clearly formulated in our minds - if we cannot translate the theory into terms that we understand - we cannot carry out deductive reasoning from the theory. So I think that precise formulation is an important goal. I understand that some important work is going on in this direction, but I have been able to keep up only to a very small extent.

I have tried to work out the connection between the INRC group and the snail problem to see how this abstract group applies to a particular problem. I would like to be able to deduce some consequences of the acquisition of the INRC structure, which characterizes the stage of formal operations, which I can test in the classroom. In fact, I have a very immediate motive for doing so. I have seen children solve problems very much like the snail problem at a very young age. The question is, can children solve the snail problem by the age of seven or eight (which seems much too young for formal operations) after a period of instruction? Is this acceleration to the formal level or is this something else that is not properly called formal? Because we think there is an apparent conflict, the question of deduction comes in.

Now, very briefly, as I understand from the literature the INRC group is a set of four operations or transformations applied to logical formulas rather than to physical objects. As I understand it, one could take any logical formula and could transform it according to each of these transformations. The first one being identity (I), if I start with $p \vee q$, then I write the formula, $p \vee q$. The second one being negation (N), if I start with $p \vee q$, I get either the negation of that, $\sim(p \vee q)$, or I write it this way: $\sim p \vee \sim q$, which can be shown equivalent by truth tables. The third transformation (R) is a little more unusual. This is the negation of both the p and the q, $\sim p \vee \sim q$. That is, I write the negation of each of the propositional variables and I keep the operator. In the last one (C), I copy the variables but I change the operator giving me $p \wedge q$. Now, if these are correct illustrations of the application of these transformations, one can set up the group multiplication table INRC, and fill it in by composition, that is, by applying each operator to the result obtained from any one of the operators and finding which operator gives the result equivalent to the two successive transformations.

	I	N	R	C
I				
N				
R				
C				

This leads to one of the two four-groups of mathematics, so these logical transformations provide a sort of definition of the INRC group. They tell me what the structure of the INRC group is.

Now the question is, how does this structure apply to the problem of the snail? The snail has two possible motions of translation, which I'll represent as S, going to the right, and $\bar{S}$ going to the left. The board similarly has two motions B and $\bar{B}$, and the question is how do the INRC operations relate to this problem? In particular, Professor Piaget gave a formula for this problem which considerably puzzled me: IN = RC = O.

One has to reinterpret somewhat the meanings of the four operations (INRC) as they apply to the four translations. Instead of using logical formulas we will use 'S', '$\bar{S}$', 'B', and '$\bar{B}$' for the snail-board operations, but interpreting these symbols as statements. 'S' means the snail moves to the right. '$\bar{S}$' means the snail moves to the left. 'B' means the board moves to the right, and '$\bar{B}$' means the board moves to the left. Now the identity transformation (I) leaves them unchanged. The negation (N) reverses the direction of motion. R reverses the directions and interchanges the objects, for example, R transforms 'B' to '¯S' and '¯B' to 'S'. C is most conveniently regarded as the composition of N and R. I won't go through the demonstration of this fact, but it gives you this: that to apply C, you first transform a statement by N and then you transform the result by R. Here is the result:

	S	¯S	B	¯B
I	S	¯S	B	¯B
N	¯S	S	¯B	B
R	¯B	B	¯S	S
C	B	¯B	S	¯S

Now if this is the correct application of this set of four operations to these snail-board statements, then from this we can derive a table predicting the results of combinations of any pair of them. Consider 'X' to be a statement describing any one of the snail-board translations. We can add these snail-board translations, and we agree to write X + N(X) = O. This means, for example, move the snail to the right, then move him to the left, and the result is the equivalent of doing nothing. We can also write, X + IN(X) = O, since the identity (I) doesn't change anything. Also, you get the same result by adding X + RC(X). For instance, you can take ¯S + RC(¯S) = ¯S + R(¯B) = ¯S + S = O. Both sums equal O, so the equations 'IN = RC = O' now make sense to me.

Now from the above table, you can in this fashion derive the table of results of any combinations of two different translations you may wish to present. For example, you may ask a child what happens if the snail moves to the right and the board moves to the left, etc. You can put each of these four translations against the others. The resulting table, which I won't take time to explain, presents the answers to all possible questions - the combinatorial analysis.

	S	¯S	B	¯B
S	▨	O	+	O
¯S	O	▨	O	-
B	+	O	▨	O
¯B	O	-	O	▨

Then my question comes to this: is it sufficient for the child to answer all of these questions separately? If the child answers all these questions correctly, is the child then at the level of formal operations? It seems to me, that quite young children after instruction or work with examples of relative motion, can answer these questions correctly.

PART III

CURRICULUM PROJECT REPORTS

3

THE SCIENCE CURRICULUM IMPROVEMENT STUDY

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The question of spontaneous development from preoperational to formal thinking as opposed to deliberate instruction to insure and accelerate this development is Karplus' topic. The aim of the Science Curriculum Improvement Study is described as that of fostering development of thinking to the formal operational level from natural philosophy to scientific literacy. Karplus, a physicist at the University of California, discusses the program of the Science Curriculum Improvement Study for grades K - 2 in Piagetian terms.

I think you will probably all agree that there is a transition between children's preoperational thinking at kindergarten age and some of their thinking in terms of propositions when the pupils leave elementary school at twelve years or so. It seems to me that in general this transition in children's thinking is not recognized by present educational practice in the United States. Teachers with whom I have been in contact have not seemed to be much aware that there is such a change taking place. And I would say that most instruction above the kindergarten takes place on what one might call the formal level. As an unfortunate consequence of this fact many students never understand the intent of instruction and become dissatisfied with school by the time they are fourteen or sixteen. There are, of course, a substantial minority who make transitions from preoperational to formal thinking due to their own intellectual capacity. Piaget has studied many examples of such children. But I maintain that there are persons who grow to adulthood without attaining the capacity to think on the formal level in very many areas of their experience. They do attain the capacity in some areas, but not in nearly so many as one should like. From my contacts with teachers I should also say that stimulus-response theory seems to have a powerful hold on them - in terms of what the teachers are accustomed to do in order to achieve the teaching aims and objectives as they see them.

There are two ways in which a curriculum effort can attempt to modify this situation. One way is to help teachers recognize the fact that if one explains matters to young children in terms of "if - then" statements, they may not understand, even though they may be able to make check marks in the correct "if" or correct "then" column of a test. It is important for teachers to learn this, to become aware of Piaget's experiments and their outcome. I think his conservation of volume study is one of the most impressive demonstrations that any teacher can carry out with children at age five, six, or seven. Those teachers to whom we have suggested it and who have tried it have been amazed. They wouldn't have believed it ahead of time.

A second way is to develop the children's ability to use formal operations. Piaget has found that this ability develops in some respects without special instruction, but it does not seem adequate to encompass the results or thinking or attitudes of modern science. Instead, there develops what I would like to call a kind of common sense or natural philosophy. The formal thinking of most youngsters in high school does not in general enable them to recognize the type of relationship one has to recognize when one makes a scientific study.

The program of the Science Curriculum Improvement Study is aimed at the second of these problems, to help the children's intellectual development reach the formal operational level with a repertory of concepts that to a certain extent is different from the repertory which is part of the common sense and the natural philosophy in the population at large. The first item, that of leading teachers to a more sensitive recognition of different stages of intellectual development is part, I think, of a teacher education program that is much broader than our own intentions.

The premise of our program is that it is possible for the school to have a conscious influence on the development of its pupils in order to produce a more significant and a more useful understanding of natural phenomena by the time they are in their teens. To this outcome we give the name "scientific literacy". Of course, one needs to define the meaning of scientific literacy or explore it in considerably more detail than I have time to do. I trust you will nevertheless recognize that it is a desirable quality. We try to go about this program by fostering development along a broad front during this roughly six-year period of quite rapid intellectual maturation -- a speed of maturation which I think is not repeated later. And the fact that some of this seems to be a pushing down of problems from later educational to earlier educational levels is a misunderstanding of what we do. If children do not receive appropriate early schooling, there are many items that they never learn -- even as adults. For example, I would say that Mr. O, the concept of relativity, is one that many adults never learn. Whether we accept it as concrete or formal is not the point. There are intellectuals and university faculty members and social scientists like us who may take it for granted that such an obvious idea as relativity is grasped by adults in general. But my contact with many members of the general public makes me realize that this is not the case. Mr. O is not something that is learned as a matter of course in the absence of special instruction. Teaching relativity in the elementary school, therefore, does not imply an acceleration of learning that is accomplished more slowly now; it implies a qualitative change in learning. And this is the way the school's influence can be most significant: the curriculum planning can include ideas which are considered to be important and which are not normally attained. Here is where I would contrast the scientific point of view with the common-sense or natural philosophy point of view. They are different, and I would like the science program in the school to develop the scientific point of view.

Our program reflects the breadth of natural phenomena at the early stages as we try to develop in children's thinking about natural phenomena a hierarchical structure of concepts that later becomes more and more sophisticated.[1] Each topic in this program represents an application of previous elements of study and at the same time lays a foundation for subsequent elements of study. For this reason our teaching experiment has to be carried out in a rather carefully controlled manner. In other words, it is impossible for us to work with a fifth grade topic in a school in which the children have not had the previous four years of instruction. In fact, if it were possible for us to work in an "untutored" fifth grade, then it would be pretty obvious that what we were doing in the fifth grade was not significantly dependent on the previous four years. Since we believe that there is a dependence -- and I think we have some evidence to support our belief -- we are conducting our experiment by starting with the kindergarten - primary grades and then adding to the experimental teaching program a higher grade each year as the children are promoted. Thus, we shall have a third year, then a fourth year, program and so on.

Let me now describe some of the topics that we have considered. The first is "Material Objects"[2] in the kindergarten and first grade program. Here the children become aware of what is material in our environment and what conservation properties material objects have. By contrast there are very many real and important things which are not material; for instance, relations of objects to one another are not themselves objects. In our experience the children are not able to distinguish very clearly between properties, relations, and the objects that are involved in these relations. In the program the children manipulate many objects having different properties. There are metals and wood, shiny objects, smooth ones, sharp ones, soft ones, liquids, powders, and gases. I would say it is a kind of natural history of material objects themselves rather than of their manufacture, or their use, or something else. A basis for this kind of unit is, of course, that the children have some concept of the conservation of objects. Since this appears to be formed when the children are very much younger, age one or two, we are, I think, fairly safe in taking this intellectual accomplishment for granted.

When we come to "Variation and Measurement",[3] the next topic for the first grade, the tasks are much more difficult because measurement involves a conservation of a property of an object with respect to various transformations - transformations that might involve displacement from one point in space to some other point, as when we move a ruler from one point to another. Its invariant length has to be recognized; otherwise comparing one ruler to many objects when measuring them doesn't particularly make sense. Piaget has shed much light on the development of these concepts. The development of concepts of variation, however, is something I have never seen discussed in the psychological literature. Our teaching program is, again, a kind of natural history in which one now does not look at a single object only, but one looks at a whole collection or sample of objects that are fairly similar to each other but which are different in some way. The objects may differ in length; or, to get the tasks down to counting or measurement in natural units, they may be pea pods and differ in the number of peas. Then the children make histograms of distributions of specific cases they encounter and find by observation that certain specimens are much more likely to be found than others.

For the second grade program, we have a unit that is called "Interaction and Systems".[4] Dr. Cronbach said that it was important to have attention-directing devices as a part of teaching. A system is a grouping of objects which belong together in some way. By choosing a system in which the children are interested and allowing them to follow this choice or selection or definition, one can direct the children's attention to certain objects and their relation. At the same time, comparison of two distinct systems is facilitated. The scientist conceptualizes a system for exactly the same reason - to confine his attention to what appears to be significant or important right now and to suppress, for the time being at least, those elements that appear distracting rather than significant. "Belonging together" is a quite subjective criterion. One sometimes, therefore, has to change his definition of "system" because experiment or observation reveals that the initial choice was inadequate.

Interaction is an interpretive concept. It is another concept that I have not seen discussed in the psychological literature, and just what role it plays in the transition from preoperational informal thinking is a question I would like to ask all of you, including Professor Piaget. It is a relation between objects. It is not an object itself. It is an interpretive concept and is important for the following reasons. As one makes observations, as one accumulates a natural history of objects or phenomena, it is possible to attach significance to the phenomena in very many different ways. (As you know, some societies attach significance to rainfall in terms of certain mythological interpretations. I dare say you cannot rationally convince someone who holds this viewpoint that it is not correct.) Modern science is characterized by a certain hierarchy of interpretations. We would like children to learn to make a scientific interpretation rather than a mythological or a superstitious interpretation of natural phenomena. We feel that it is a responsibility of the teaching program to introduce these scientific interpretations. One of these is to interpret any change as an evidence of interaction. Interaction is a fundamental scientific explanatory concept. We don't say that a change, a happening, is evidence of mythological processes as it was once thought to be, but we say it is evidence of interaction, interaction being a certain relationship. In other words, interaction of certain objects is the cause of a happening. This, then, is our second-grade interpretation of Newton's second law.

In order to introduce this idea into the curriculum we have used a pedagogical device which is called "Invention and Discovery".[5] The way in which this pedagogical device (and again I am not quite sure about what is the relationship between this and various SR or non-SR learning theories) functions is this: there is an instructional period consisting of several class sessions, in which the children are engaged in observation on a natural history level of some new or some familiar materials with which they "play". There is then a suggestion (invention) of a way to think about the observations. Finally, there is further experimentation in which the children can explore the consequences of using the suggestion (discovery). In "Interaction and Systems" the materials might be magnets and nails, some dry cells and light bulbs, etc. -- more or less common materials with which one can do simple experiments. We then suggest to the children that they should think about the changes they observe as being evidence of interaction. The remarkable thing is that the children do learn to think of it this way and that during a later experiment they run up to the teacher and say, "Look, there is some evidence of interaction." Thus, "invention" is an introduction of an interpretive construct and "discovery" is a recognition of the usefulness of the construct. What we have here is a guided discovery, a process of going from observation at the beginning to interpretation at the end through the device of "Invention and Discovery".

Now, I believe Piaget has pointed out that in the natural development of a child his own initiative to shape his explorations and to decide what he will do is dependent upon the child -- the child decides. I think that this econnmy of decision is a significant element which determines the quality of the learning that occurs. The question we therefore face is, how much help can one give the child without depriving him of his decision-making initiative to such a large extent that he would never recognize when a particular idea really works out? The Science Curriculum Improvement Study's compromise is to have the teacher provide the construct, but to leave ample opportunity for the children to apply the construct to many cases in their own manipulation.

The second item for the second grade is the unit on relativity.[6,7] Since this has already been discussed a number of times, I will not go into further detail now. Instead, I should like to present a more speculative discussion.

Let me consider the distinction between observation and interpretation in general. Is this distinction meaningful? For example, I mentioned earlier that interaction is an interpretive concept. It is not something that can be directly observed, but it is inferred from observed evidence. I think the distinction is meaningful, but I also think it must be kept flexible and that it may not hold for all individuals in the same way. What is an interpretation for one individual may be completely assimilated and an obvious part of an observation for another. If this is correct, then it raises another obstacle to effective communication between teacher and students, whose different degrees of sophistication make them distinguish differently between observation and interpretation. In science, where the distinction between objective, observable fact and hypothetical, interpretive theory is frequently made, the difficulty is likely to be particularly acute.

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THE ELEMENTARY SCIENCE STUDY BRANCH OF EDUCATIONAL SERVICES INCORPORATED

Eleanor Duckworth

Educational Services Incorporated

Goals and activities of the Elementary Science Study Branch of Educational Services Incorporated are discussed in this paper by Eleanor Duckworth. As in other curriculum projects the influence of psychological approaches is seen to be minimal. However, procedures are judged to be psychologically sound. Additional comments by Ben Nichols on his work with electricity in the fourth grade provide a specific example of the work being done at ESI.

The Elementary Science Study Project is a branch of Educational Services, Incorporated. ESI is also the parent body of the PSSC high school physics. The elementary school science project is an interdisciplinary one, or in many cases, predisciplinary. It started about two years ago and had its initial conference in the summer of 1962 where there were close to 100 participants, most of them university scientists, with elementary school teachers, a number of psychologists, and others. Since then, a permanent staff of about 15 scientists and teachers have continued work in our Watertown, Massachusetts office, and increasing numbers of teachers throughout the country are contributing additions and modifications on the basis of their trial teaching.

A good deal of our effort is directed toward the creation of materials which are appropriate for children's science learning. There are a number of requisites for these materials. They must be inexpensive, so that each child in a class, or at least each pair of children, can work individually. They must be simple enough so their functioning is clear, and children can raise their own questions about the materials and use them to find their own answers. They must be rich enough in possibilities so that initial questions can lead to problems of greater demand and significance.

There are always two aspects to the development of these materials. One part takes place in our laboratories. The other part takes place with children and teachers in the classroom. Anything which we produce in the way of materials or of outlines and suggestions for their use is based on trial and exploration in many different classroom situations, where the children themselves have been the most important factor in the assessment.

I shall try to direct my remarks about our work to make them relevant to the topic of this conference. First of all, I will mention the extent to which there has been direct influence of cognitive research in our work, and that extent has been quite limited. There are two members whose primary academic preparation is in the field of psychology. One, Bill Hull, has been especially interested in concept formation. He has developed a set of small wooden blocks with an endless variety of games, exercises, and puzzles that range from a four-year-old level to challenges for adults. Children spend long periods of time by themselves, in small groups, or with a teacher, happily passing back and forth from highly structured classification and relationship games to free and whimsical construction. Indications are that these children develop a high degree of ability in thinking about classes and relationships in general, as a result of their activities with these blocks.

Eleanor Duckworth is the other person whose background is essentially psychology. She has done several things which stemmed directly from this background. One was to search for activities for small children in which some constancy remained in spite of transformations since this seems to be an essential and a central notion. This led to the development of floating color tubes. They consist of two or three layers of colored immiscible liquids, and of small bits of plastic, rubber, seeds, etc., floating at the interfaces. In sealed tubes, they prove to be appreciated by small children on a number of levels: as simply something to shake, or providing beautiful bubbles and droplets to watch, or bringing the realization that they always come back to the same way they were before shaking, or that the same layer is on top--the same on the bottom, no matter which way the tube may be turned.

Happily enough, although this was not the original idea, it has turned out that older children enjoy creating such tubes for themselves, and this involves thinking about immiscibility, density, and staining, as well as demanding a highly systematic approach in order to keep all the information straight and get as many layers as possible.

Well, these are two instances in which some sort of background in cognitive research has been relevant to development of some specific items. Apart from that, the psychologists play a general role in teaching and in evaluating the way children are learning from the materials.

Most of the other members of the staff have a different starting point, rather than the psychological significance of the activities involved. Some have a particular interest in teaching some subject matter area. For instance, Ben Nichols, professor of electrical engineering at Cornell University, has been working on teaching electricity. In other instances some subject matter may seem exceedingly simple and available for children to examine; for instance, watching mold grow on foods, and trying to slow down or accelerate this growth. In other cases the type of scientific investigation involved has general significance, for instance, studying the behavior of meal worms because it is a good way to get directly involved in the study of animal behavior.

In most of these, appeal is not made specifically to psychology either for the grade level at which to try the material or for the soundest way of presenting it. But somehow the psychological basis does often turn out to be sound. This is no doubt partly because the findings in the world of psychology, like those of Piaget, have had some influence on people's ideas about what makes for good learning. At any rate, the general guidelines of most of the work done at the Elementary Science Study Project does prove to have characteristics of good teaching.

There are two main characteristics which we keep in mind. One is that the children use materials themselves, individually or in small groups, often raising the questions themselves, answering them in their own way, using the materials in ways the teacher had not anticipated, coming to their own conclusions. In Piaget's terms, they are acting on things, transforming things, and learning about them by seeing the effects of these actions and transformations. The other is that we try to create situations where the children are called upon to talk to each other. One of Piaget's fundamental notions is that of egocentrism which is characteristic of small children. We might say this means not realizing that there might be some point of view different from their own. Because of this, children and even adults are often led to misread data, to assimilate it to what they think already, and then be happy with the way they read it. Several different children may see the same thing in several quite different ways. Called upon to discuss their differences and seek agreement on what really happens, they lose some of their complacency with their own first ideas.

In the time that is left, I would like to mention some of the other aspects of work at the Elementary Science Study Project. We are making some films for use in classrooms. Most of them are silent three minute film loops of phenomena where children can see things in the film that they could not otherwise see. They can replay these few minutes as often as they wish, to look more closely, think about them again, and so on. Some of us are making a survey of written material for children in a specific subject matter area and are making a critical bibliography. Some are writing supplemental material for children and for teachers.

Additional Comments

Ben Nichols
Professor, Electrical Engineering
Cornell University

I shall describe briefly an example to give a feeling of the kind of thing we do in working with children and electricity. In a fourth grade class, say, children would start out with a flashlight battery and bulb. The initial problem simply would be to use those to find out what it requires to light the bulb. Each child would have his own battery, bulb, and he would fairly quickly ask for some wire. Eventually they are all lighting their bulbs and finding out ways that work and ways that do not work. Having done that, they might be given a battery, a bulb, and some wire, and see what else they could put in that would still allow the bulb to light. A box of things may be provided by the teacher, but in addition there are all the things in the classroom which they may try. This leads to a very busy time classifying which things will and which things will not light the bulb. One of the things in the box is a little switch. The children try this out and in this process they usually come upon three different ways it can be connected. In one, the switch must be open for the bulb to light; in another it must be closed; in the third, the bulb will light whether the switch is open or closed. Now all of these are different findings with the same piece of material, which leads to a lot of lively exchange of opinion. This in turn leads to a whole host of questions.

The main point I want to make is that the choice of materials and the way they are used aims to have each child actively participating and aims to set up situations in which a lot of different things will be found out and which actually lead to very significant concepts in learning about electricity.

A.A.A.S. COMMISSION ON SCIENCE EDUCATION CURRICULUM MATERIALS

Margaret Efraemson

A.A.A.S. Commission on Science Education

The author, Margaret Efraemson, is principal of the Walton Elementary School in Philadelphia, Pennsylvania and a member of the A.A.A.S. Commission on Science Education. She presents a brief overview of the Commission's program with an emphasis on curriculum materials and development.

The American Association for the Advancement of Science has set up a Commission on Teacher Education. The Commission has many interests in the whole sweep of science education. This is a brief report on our curriculum materials, both those available and those planned for the immediate future. One feature of our materials is that we are building them from the kindergarten up through the grades. This is presently unique among the new programs. Another even more unique feature is that we are approaching science education in terms of the processes of science. In our program the achievements of the children will be measured primarily in terms of their conquest of specific steps in building basic knowledges: observing and classifying, describing, recognizing and using numbers and number relations, recognizing and using space and time relations, measuring, communicating, inferring, and predicting. The relationship of the instructional materials to these competencies is indicated by terms such as observation, measurement, and numbers appearing along with the individual title in each separate exercise.

In the summer of 1963 a group of writers from various parts of the country assembled at Stanford University for eight weeks to prepare materials planned for kindergarten through grade three. Among the 35 members of the writing group were college and university people representing the major science fields, including mathematics, psychology, and science education, elementary school teachers, science consultants and elementary school administrators. Two demonstration classes, one of kindergarten and the other of first and second grade children tried out the exercises while the writers were in session. During the 1963-64 school year one hundred twenty teachers throughout the country tested the materials.

At present these A.A.A.S. K-3 materials consist of five separate parts and include more than 100 exercises or units drawn from a variety of science fields. They are arranged as an orderly progression of learning experiences. The objectives and the student behavior which is expected by the time each exercise is completed are clearly specified. To ensure that these objectives have been attained an associated appraisal exercise is provided for each unit. In a sense some of the activities, inter-disciplinary in nature, may be considered pre-science, since they are developing behaviors which will be utilized in later science learning.

The selection of the processes stressed so far in the program has a psychological, developmental basis. By asking ourselves what kinds of activities or behaviors a young child can perform at a given stage in his cognitive and physical development, the writers created a schemata on which was ordered the sequence of exercises. Young children, we said, learn by observation, by using their senses and by extending the use of their sensori-motor abilities. They learn to use number and space/time relations. Later they classify, predict, and infer.

The subject matter in the exercises is subordinated to the major goal of getting the child to think and to experience for himself a behavior which would make him aware of the processes as vehicles for acquiring and internalizing his present and future learning.

In-service orientation and education in the use of the materials has been conducted in each of the thirteen centers. A science consultant has been available to counsel and aid the teachers who meet bi-monthly.

In the summer of 1964-65 the materials will be revised and extended upward through the fifth grade. These will again be tested during the coming year in widely scattered and varied centers throughout the nation.

Additional Comments

William Kessen
Yale University

I should like to add a few words which do not deal directly with curriculum, because I think that Margaret has stated AAAS' curriculum intentions very well. The Commission has, perhaps as its most important function, that of communication. So many projects in science education have been begun in the last several years that I think we all feel that the developments are getting away from us. The Commission will serve a very useful purpose in letting everybody know what everybody else is doing, and even more important, in maintaining what can be called a Subdivision on Mediation. I hope that the Commission will be the place where we can haul people away from their jobs for a while and tell them, "Don't build curriculum and don't build blocks but think about what science education ought to be." As a more technical aid to communication, the Commission has established at the University of Maryland a library of science education materials for use by all workers in science education.

CONCEPTS IN BIOLOGY

Herbert L. Mason

University of California

Mason discusses his work in attempting to teach concepts in biology to primary grade children. As a key to the understanding of these concepts he sees a need for filling the vacuum that lies between mathematics and the material world. Results obtained from working with children in terms of applying mathematics to biology are encouraging.

I became involved in this project entirely out of my own frustrations with my own science. Being a biologist, I found that I wasn't getting anywhere with my subject and I couldn't understand why. I turned to some of my friends in the humanities and they indicated that perhaps my problem was in semantics. So I took a course in semantics and learned something about the truth matrices. This led me into symbolic logic which in turn led me into the foundations of mathematics. After having these little exercises on my own I returned to my subject to see if I could understand it. I discovered a vacuum that lies between mathematics and the material world. Nobody is training anybody to cross that vacuum. The kind of thing I am talking about is Einstein's discovery that time and space were not things into which objects were placed; rather, they were dimensions--the time-space dimensions of the objects themselves. In other words, what I am concerned with is that the youngsters somehow or somewhere in their training learn to recognize the different kinds of concepts they are working with, not to treat them all just as one kind of concept.

We in biology have been frustrated by the species concept for nearly 2,000 years. It has changed radically in its use in those 2,000 years. We still define it in the sense of Aristotle. We actually are using it in the sense of an ordinal number. When the geneticists came along they made the circle complete, returning to Aristotle but applying the properties of the breeding system. We never dropped anything, we just piled confusion on confusion.

You can understand why we have been confused about the species for this length of time. Nobody in the biological world seems to know how to analyze that concept and see what is involved in it. We have many other concepts of this kind. We are doing what is frequent in every concept of measurement. It seems the inevitable fate of every concept of measurement to go through its history of being regarded as a thing. We have the notion of "type," for example, to which the average biologist will refer as a kind of mysticism. Here they are confusing a concept of measure with a material instance of a concept. When you reach the generalization, it is a number that is serial in its nature. When it is analyzed, it becomes a model of a system of measurement such as we have never had in biology.

We have always borrowed our systems of measurement from the physicists. It is time now that we grow up and see if we can develop some systems of measurement of our own. The road to this is through the analysis of our concepts. I do not know where one teaches these matters. But I am trying to learn. People in learning theory may know about these things, but I don't, so what I have to say may appear to be very naive. This doesn't bother me in the least. I learned long ago to cherish my mistakes because that is the best way to learn. So if I say a lot of things today that seem very commonplace to you, please be charitable; I will learn in the course of time.

My own concern with the youngsters I work with is where to begin to teach this sort of thing. I have been doing some experimenting and I have been amazed by what the youngsters down in the second grade can do. In botany, of course, I must begin by teaching them the ordinary parts of a plant: the stems, the roots, leaves, and buds. After they have learned these, I call their attention to the fact that every leaf has a bud in the axil. This is called an "ordered pair."

If you will look at a tree with ten or 20 thousand leaves on it you will find that every normal leaf has a bud in its axil. The leaf lies between the root and the bud, and the bud lies between the leaf and the tip. I asked the children to map that relation on a stick. All of them could do it. Thus, they can map a concept on a stick. Then I call to their attention that the root precedes the leaf, precedes the bud, precedes the tip as you go up the stick to indicate an ordered formula. They had just been introduced to equations two weeks before. One little youngster said, "This is just like an equation." Of course, there are some differences, naturally, but none the less, it is a mathematical statement that they have become aware of.

Then we give them a notation to represent these things, r precedes l, precedes b, precedes t. Next, we say, "We want you to use this little model, this little map you have made, to discover hidden knowledge." In the first exercise we give them an ordinary willow stem about four inches long. We selected the stems so that they are just about as thick at one end as the other. We told them, "Place the sticks on your desk according to your model so that the base is on the desk and the tip is in the air." Two of them missed it; all of the rest were able to do it. Of the two that missed, one was just careless. She knew the answer, but the other one was confused. All of the rest of them got it and knew why they were right.

The next thing we gave them was an ordinary white potato and said, apply your formula now to the white potato and see what the potato tells you. The teacher was told she was not to ask them any questions except, "What else does the potato tell you?'' The first question was, ''Do you see anything that looks familiar?'' One little girl said, ''I think I see something that looks like a bud.'' A little boy said, ''Oh, that's just an eye.'' He did us a very great service because he gave us a vocabulary to work with. Then a youngster frantically waved his hand and said, ''If the eye of a potato is a bud, according to my model the eyebrow is a leaf scar.'' He was using his mathematical model to arrive at something that never occurred to him before. The next youngster said, ''If the eye of the potato is a bud, and the eyebrow is a leaf scar, the potato must have a base and a tip.'' He made this deduction by being prodded only to see what else he could discover.

The teacher then said, ''Place the potato before you on your desk so that the base is at your right hand, the tip is on the left.'' There were 39 youngsters and 39 got it right. They could use this model in the second grade to reach effective answers. I was wholly unprepared for this sort of thing and I'm anxious to get farther along with it. We are going to develop a unit on the flower, where we'll use the notion of ''symmetry'' and departures from symmetry in the flower. Again, we'll approach it from the point of view of a mathematical map and see what we can learn by way of deductions from it.

Some people object, ''Why should you do this in terms of deduction? Why shouldn't you go into induction?'' All we have to do is to seek the source of the implication and we are on an inductive basis. We can combine the two, and we actually do do this. We seek to discover what it was about the model that made the facts of the potato clear to the youngsters. What we have done is something that the biologist says can't be done, namely, apply mathematics to biology. I am tired of trying to teach college students this sort of thing because they have too much to unlearn. They are already too closely tied to everything that they have had in the past and cannot give it up. These youngsters in the second grade seem to have no problems; they love it. I think there is going to be no problem until they reach college. Then they will have to face their untrained college professor. I don't know what will happen then because he is going to be bewildered by them.

Now let me return to my first point. The matter of reaching these concepts that bridge the gap between mathematics and the material world is very important. This is why the average non-mathematician fears mathematics. It is also why the average mathematician fears applied mathematics because it is just as foreign to him as to others. We must discover what these concepts are and how to teach them to youngsters.

COGNITIVE THEORY AND THE SMSG PROGRAM

Jeremy Kilpatrick

School Mathematics Study Group

Kilpatrick describes the curriculum program of the School Mathematics Study Group and its philosophy. Mathematical structure, rather than psychological theory, has played the instrumental role in shaping the program. An interesting issue is joined, essentially the same issue provoked by the Karplus paper--i.e., the issue of spontaneous development in children's thinking versus acceleration of this development through formal instruction and altering the child's experience. The compatibility of certain features of the SMSG curriculum with the results of Piaget's studies are enumerated. The paper concludes with a discussion of the National Longitudinal Study of Mathematical Abilities.

Now that the first wave of curriculum reform in school science and mathematics has reached and passed its crest, those of us involved in curriculum development are beginning to investigate some of the psychological assumptions implicit in what we have done. The School Mathematics Study Group, in particular, is now attempting to identify components of mathematical abilities--both to assess the new mathematics curricula and to give direction to further reform. I would like to sketch for you some of the aspects of SMSG's work which are related to recent developments in cognitive theory. First, I will discuss briefly the philosophy of the SMSG curriculum program; then I will describe SMSG's National Longitudinal Study of Mathematical Abilities.

SMSG was initiated in the spring of 1958 as a nation-wide project for the improvement of the teaching of mathematics in the schools. Until recently, its chief concern has been the preparation of textbooks for grade levels from kindergarten through grade twelve. Other activities have included the production of teacher-training materials, publication of a series of monographs on various mathematical topics, and the translation of certain SMSG texts into Spanish. But the preparation of textbooks was SMSG's first, and for a long time its major, activity.

The procedure used by SMSG in the preparation of these texts has been a novel one. Large teams composed of equal numbers of mathematicians and classroom teachers work intensively for a relatively short time, usually a summer session of about eight weeks, on the development of an experimental text. This preliminary version of the text is tried out during the school year at experimental centers across the country and revised by a similar team during the following summer. The general pattern has been for the mathematicians to suggest the mathematical content to be included in the texts and for the classroom teachers to suggest how it might be presented at a given grade level.

The philosophy of the writing teams is suggested by the following excerpt from the first SMSG Newsletter, March 1959: "We need an improved curriculum which will offer students not only the basic mathematical skills but also a deeper understanding of the basic concepts and structure of mathematics."

These writing teams have not worked in ignorance of contemporary learning theory, but neither can it be said that they have been guided at every step by any explicit body of psychological knowledge. Their goals have been more logical than psychological. They have attempted at every point to make mathematical structure the focus of their concern and they have made their own experience rather than predictions from psychological theory the test of whether and how a given topic can be taught at a given grade level. It is significant, I think, that none of the changes made in the revised SMSG texts are changes in the basic mathematics or philosophy of the original material.

In a sense, the mathematicians who have guided the recent curriculum reforms have been waiting to be shown that psychological theories of learning and intelligence have something relevant to say about how mathematics shall be taught in the schools. These reformers (and I speak now not only of SMSG) have been so successful in teaching relatively complex mathematical ideas to young children, and thus doing considerable violence to some old notions about readiness, that they have become highly optimistic about what mathematics can and should be taught in the early grades. This optimism, if I may call it that, is reflected in the recent publication Goals for School Mathematics, the report of the Cambridge Conference on School Mathematics, held last summer at Cambridge, Massachusetts. This report calls for a major reorganization of the grade school curriculum and a compression of high school and college offerings. It deals only with the problem of organizing the mathematics curriculum, not with teaching methods. Its purpose is to anticipate another major curriculum reform to start in the next twenty to thirty years. I quote from the introduction to the report:

> "We made no attempt to take account of recent researches in cognitive psychology. It has been argued by Piaget and others that certain ideas and degrees of abstraction cannot be learned until certain ages. We regard this question as open, partly because there are cognitive psychologists on both sides of it, and partly because the investigations of Piaget, taken at face value, do not justify any conclusion relevant to our task. The point is that Piaget is not a

> teacher but an observer--he has tried to find out what it is that children understand, at a given age, when they have been taught in conventional ways. The essence of our enterprise is to alter the data which have formed, so far, the basis of his research. If teaching furnishes experiences which few children now have, then in the future such observers as Piaget may observe quite different things. We therefore believe that no predictions, either positive or negative, are justified, and that the only way to find out when and how various things can be taught is to try various ways of teaching them."

I think this quotation reveals the attitude of many mathematicians as they approach the problems of curriculum reform, and it also indicates some of the questions that educational psychology will have to face in the near future.

Jerome S. Bruner, in his book The Process of Education, has provided a psychological rationale for the major ideas of the new math curricula. Since much of his interpretation of new concepts and methods in education is made in the light of what Piaget has said about intellectual development, Bruner has stimulated considerable interest among math educators and mathematicians in Piaget's recent work. Bruner's discussion of the spiral curriculum and the importance of emphasizing the structure of a subject has been especially well received.

Let us look briefly at those features of the SMSG curriculum that are most harmonious with the results of Piaget's studies. First, there is the grade placement of certain topics. Piaget's evidence that the child of nine or ten can handle many of the basic concepts of Euclidian spatial representation and measurement is mirrored in SMSG's placement of such topics in the elementary curriculum. His findings on the development of the concept of number are similarly shown in the emphasis on correspondences and relations among sets in the SMSG elementary curriculum, although we may have failed to anticipate some of the subtle misconstructions of a concept which Piaget has demonstrated can and do occur. Next, there is Piaget's emphasis on the participation of the learner as he performs real actions on the learning materials. This is shown in SMSG's use of discovery exercises in all of its text materials, but we have certainly not begun to realize the possibilities in concrete sensory aids. The work of Z. P. Dienes of the University of Adelaide is especially promising in this regard. We are looking forward with interest to Bruner's report on the recent research he and Dienes have done at Harvard's Center for Cognitive Studies. A final parallel between Piaget's studies and the SMSG curriculum can be found in SMSG's emphasis upon learning the structure of the subject matter. For example, the properties of reversability and associativity are, in Piaget's theory, important features of operational systems. The SMSG curriculum gives the student ample opportunity to practice operations with these properties in the expectation that he will then become sensitive to cause - effect relations in mathematics and to the idea that there can be many routes to a goal.

Before leaving the subject of the SMSG curriculum, may I point again to the mathematician's belief in the possibility of radically altering the stages Piaget has observed in intellectual development by changing the child's previous experience. It would be no profound blow to Piaget's theory if the age levels of the stages were influenced by experimental manipulation, but it would be a serious matter if the sequence of stages was somehow rearranged. Considerable research in the near future is certain to be centered on this issue of finding "elastic limits" in children's cognitive processes.

Now I should like to discuss SMSG's testing program -- in particular, the National Longitudinal Study of Mathematical Abilities.

There has been in recent years a growing recognition that the mathematics which students study in school is a continuous stream rather than a collection of discrete units and that detailed information about the processes involved in school learning is best gathered through a longitudinal study. Piaget's and Inhelder's work amply testifies to the value of a longitudinal approach.

The National Longitudinal Study of Mathematical Abilities, or NLSMA, was undertaken in 1962 as a five-year study. Its purpose is to discover the variables which affect mathematical learning and, in particular, to assess the effectiveness of various curricula.

During the fall of 1962, schools participating in NLSMA gave an initial battery of four inventories to a total of 122,000 fourth, seventh, and tenth-grade students in both conventional and new mathematics curricula. The battery consisted of standard intelligence test items, together with tests of attitudes with respect to mathematics, and preferred conceptualization strategies. These variables were chosen as salient for assessing some of the individual difference variables which may interact with the growth of mathematical skills.

Jerome Kagan, a member of the SMSG Panel on Tests-the group responsible for the design of the study and for the selection and construction of tests-has provided the following rationale for the choice of instruments in this initial battery:

"...ease of learning new material--and this is the major variable in the NLSMA--is the function of three major classes of psychological variables: (a) degree of attention given to new material; (b) possession of those cognitive structures necessary for comprehension of new material; and (c) conditions of presentation of material (e.g., tempo of presentation, (and) feedback of results..."

"The degree of attention invested in material to be learned is a function of motivational variables, anxiety, identification with specific sex role models, and cognitive strategies. The variables of importance with respect to possession of structures include vocabulary level and knowledge of the transformational rules appropriate to the material. The conditions of presentation have to do with the speed of presenting new materials, the degree of structuring of material (e.g., how big a unit is presented), and the importance of immediate reward or feedback of results."

"It is, of course, impossible to assess all of these variables, and we chose to concentrate upon those that appeared to be most relevant for the differential mastery of mathematics and chose tests that were amenable to large-scale group administration."

Additional individual difference variables were measured last fall, when the NLSMA population was divided into three sub-populations matched on demographic and intellectual characteristics. Each sub-population was given tests of arithmetic reasoning, general reasoning, and other tests taken primarily from French's Revised Kit of Reference Tests for Cognitive Factors. The tests which were used were tests which had shown up as relevant in previous factor-analytic studies of mathematical abilities.

Measures of mathematical abilities had been given to the NLSMA population in the spring of 1963 when the mathematics section of the Sequential Tests of Educational Progress and other mathematics inventories were administered.

This spring we are attempting an even more comprehensive assessment of mathematical abilities. Three class hours of testing time will be devoted to the assessment of all levels of mathematical skills. The tests that will be given are the culmination of over a year's efforts. First, we tried to identify the basic mathematical topics that students are expected to master at each grade level. Then, we classified test items on these topics according to a system of cognitive skills based on the Taxonomy of Educational Objectives: Handbook 1: Cognitive Domain. The taxonomy orders cognitive skills into six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. Our ordering of mathematical abilities differs only slightly: knowing, translating, manipulating, choosing, analyzing, synthesizing, and evaluating.

When we examined test items from standard mathematics tests, we found that only a few of them tested skills above the level of choosing. We wrote a group of items illustrative of the various levels and then last summer at Stanford we held a summer writing session. During the month of July a group composed of six college teachers of mathematics, six high school teachers of mathematics, and a psychologist met to create test items. They presented ideas for testing the higher cognitive skills, including aspects of problem-solving and of creativity. Most of the ideas submitted for tests deal with topics in mathematics unfamiliar to students. In such tests, students would be asked to read and analyze new mathematical information and then to apply it to a problem. Some of the tests were pre-tested with students during the summer.

At a Chicago meeting in September, forty college mathematicians and educators reviewed the preliminary study and the work of the Summer Writing Session. They clarified the taxonomy and the mathematical topics for each grade level and selected forty-five of the sixty-four tests developed during the summer as being worth development.

In October the SMSG Sub-Committee on Mathematical Tests met and approved the work of this conference. In addition, the Committee decided to construct tests emphasizing number systems for the fifth grade; number systems, informal geometry, and algebraic concepts for the eighth grade; and algebraic sentences and formal geometry for the eleventh grade. Tentative items were collected from the Summer Writing Session, the University of Illinois Committee on School Mathematics, the Minnesota Testing Laboratory, the Educational Testing Service, and individual writers.

The sub-committee, along with several consultants, met again in January to review the items and to place them into tests for pilot-testing. More than sixty tests were devised and administered to 25,000 students in thirty-four states. These pilot tests have been analyzed, and we have just concluded the preparation of the spring battery of tests using those items which showed up well in the pilot-testing.

Soon we will be making plans for the final three years of the study. Analysis of data already collected will be used to guide future testing. We also plan a number of small-scale research studies which may then be incorporated into the longitudinal study.

One area of present concern to us is the detection of cognitive styles of handling mathematical concepts. We are particularly interested in systematic versus non-systematic styles. We have developed some tests designed to detect students who approach mathematical problems in a systematic manner, but these tests will require a great deal of work before we can make inferences about cognitive styles with any confidence. This is, nonetheless, an area in which we have reason to feel some hope of uncovering cognitive variables associated with mathematical abilities. The work of John W. French on The Relationship of Problem-Solving Styles to the Factor Composition of Tests, in which he found that the use of a systematic style on a test frequently reduced its loading on the factor with which it is usually associated, has been of great interest to us.

Three years of the longitudinal study remain. We hope that in that time we can gather information about the processes involved in mathematical performance that will contribute to cognitive theory as well as lead to a better and more satisfying mathematics program for future generations of students.

SOME REMARKS ON A THEORY OF INSTRUCTION

Robert B. Davis

Syracuse University and Webster College

Seeding his paper with provocative examples, Davis explains the Madison Project in mathematics. The rationale for the Project is set in the context of a "theory of instruction" which has implications for other curriculum areas. The relationship of Project activities to Piaget's approach is discussed as is the relevance of his concepts of assimilation and accommodation.

Speaking from notes, I have several points to mention.

1. The Madison Project's "Informal Exploratory Experiences."

The Madison Project of Syracuse University and Webster College is a "curriculum revision" project, sponsored mainly by the National Science Foundation and the U. S. Office of Education, and concerned mainly with the learning of mathematical ideas by children from nursery school through high school (chronological ages three years to 18 years).

The Project is concerned primarily with establishing a more creative flavor for school experiences in mathematics, with extending the range of mathematical topics which are included in the school program, and with rationalizing the historically - created disorder in notation, definitions, sequence of topics, and so forth, within the mathematics itself. The Project devises mathematical experiences for children, and records these experiences by means of motion picture films showing actual classroom lessons.

These lessons have many novel aspects - indeed, so much so that they have often been misunderstood by observers who sought to identify a traditional structure within the lesson. In order to gain some semantic clarification, we have given our lessons a special designation: "informal exploratory experiences." This name seems to relieve the minds of some observers, who now feel less need to identify a traditional lesson format.

Descriptions of these "informal exploratory experiences" have been given elsewhere; probably the best way to approach them is by viewing some of the Project films.[1] Among other things, "informal exploratory experiences" are usually characterized by lively student participation, a relative absence of exposition by the teacher, a relatively democratic, informal, non-authoritarian tone, a relative absence of external rewards, and an unusually low anxiety level.

2. Two Kinds of Student Activities.

In looking over various Project lessons, one finds that most of these lessons are of one of two types: those in which children gain experience by doing something - such as guessing the measure of an angle, and then checking their guess by measurement with a protractor - or else those in which a group of children pursue a seminar-type discussion, unobtrusively guided by the teacher. In this second case - the "discussion" type of lesson - it is usual for the discussion to proceed by considering a sequence of questions, one after another. The analysis of this sequence of questions is of considerable interest, and is the subject of my next remark.

3. "Sequencing" and "Elementary Ideas": Flexible Program Construction.

Studying "discussion" type lessons, either live or on film[2], one notices that the precise sequence of questions is of considerable importance. If these questions are asked in a slightly different order, or in slightly different combinations, the lesson does not proceed equally smoothly. This appears to indicate a considerable rigidity in arranging lessons, and for some time we wondered how to reconcile this apparent rigidity with the spontaneity and flexibility which also seem to be attributes of well-taught Madison Project lessons.

We have gradually realized that the explanation is essentially this: The successful Madison Project teacher possesses the ability to construct quickly, in his head, a kind of programmed sequence of questions that builds carefully from one idea to the next. He is also attentive to cues from the class which indicate when to abandon his present sequence of questions, and to replace it, or supplement it, with a new programmed sequence which he devises quickly, in his head, upon perceiving the need for it.

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[1] Films useful for this purpose include: A Lesson With Second Graders, First Lesson, Second Lesson, Matrices, Creative Learning Experiences, Postman Stories, Graphing an Ellipse, Solving Equations with Matrices, Average and Variance, Sequencing and Elementary Ideas, and Complex Numbers via Matrices. Prints of these films may be obtained from: The Madison Project, Webster College, St. Louis 19, Missouri.

[2] Cf., for example, the films A Lesson With Second Graders, First Lesson, Discovery, and Sequencing and Elementary Ideas.

The process of breaking a big mathematical idea - for example, the idea of quadratic equations - down into a sequence of small ideas is, we believe, a delicate one, and must be done with careful regard for the crucial mathematical decision points. When these small ideas have been correctly identified, we call them elementary ideas. They are the true "atoms" from which the "molecules" of mathematical thought are made up.

As an analogy, consider leaving your office and walking to your car. If this idea - which we might call the big idea of going to your car - is to be broken up into small pieces, we can do it in many ways. Some of these ways respect the true decision points, while others do not. One might break it up into such small ideas as: "get up from chair," "move left foot," "move right foot" (repeated many times), "put key in lock of office door," "turn key," "remove key from lock," "put key in pocket," . . . and so on. These, for a normal adult, do not remotely approximate the small decisions that must be made.

By contrast, consider a sequence such as this: "check to see if there are any parcels to take home," "make sure office door is locked," "remember where you left the car," . . . and so on. This comes much closer to respecting the true decision points for a normal adult generally familiar with the building in which he has an office.

Analogous alternatives exist in identifying elementary ideas, and it is our opinion that considerable programming in mathematics approximates the disastrous first example rather than the more appropriate second example.

Notice that while I have spoken of programmed instruction, the programs do not ordinarily exist on paper; they are usually made up, in his head, by the teacher, and used as an unobtrusive guide for class discussions. What actually occurs is an apparently spontaneous informal seminar-type discussion, in which the teacher's role is important but relatively unobtrusive. The language of programmed instruction has been used here in an attempt to analyze one aspect of these discussions.

One type of question sequence is of special interest; we shall discuss this in the next section.

4. "Error Correction" Sequences.

In the filmed lesson entitled A Lesson With Second Graders, the teacher asks "What can I write in the box to make this

$$^{+}5 + \square = {}^{+}3$$

a true statement?" One student, Charlotte, answers "$^{+}2$". How is the teacher to deal with this student error? We seek never to settle mathematical questions by teacher (or textbook) authority; on the contrary, we want the students to develop autonomous decision procedures which let them decide for themselves the correctness or incorrectness of any answer. Mathematical truth should be found by scrutinizing the structure of mathematics, not by scrutinizing the face of the teacher, nor the page of a textbook.

In the filmed lesson, the teacher responds by asking another question: How much is $^{+}5 + ^{+}2$?" Charlotte answers "positive seven," and immediately wishes to reconsider her previous answer. Her next attempt is successful.

This is an example of what we have called error correction sequences. They play an important role in effective Madison Project teaching.

5. Intrinsic Motivation.

I can cover this point briefly, by saying that we seek mathematical tasks that possess what Wolfgang Kohler has referred to as "demand quality" - the motivation is contained within the task, rather than in the external social context. (Nonetheless, we admit that external motivating factors are present - especially the desire to perform well in front of one's friends.)

6. Cognitive Structures and Mental Symbol Systems.

The theoretical approach of Professor Piaget is especially relevant to Madison Project teaching because of Piaget's emphasis upon a sequence of cognitive structures,

$$\ldots, C_n, C_{n+1}, C_{n+2}, \ldots$$

where the goal for each new learning experience is either to add detail to the student's present cognitive structure (by assimilation), or to cause the student to discard his present cognitive structure and to replace it by a new one (the process of accommodation). This general approach is central to Madison Project teaching, and has a very long list of implications and corollaries. Let me refer to it briefly in terms not of mathematics, but in the analogous situation of learning the map of a new city.

One's ideas of the city's streets will necessarily be erroneous, at least in detail, and sometimes in major features. The child learning mathematics often behaves as if he were scrutinizing such a map inside his mind: he may suddenly announce a newly-discovered implication of his map ("Why, I'll bet if you go far enough out Commonwealth Avenue you'll come to Route 128."), he may seek to fill in detail for some portion of his map, and so on. This requires that the child have considerable autonomy in selecting his questions and his tasks - if he is required to conform to externally-assigned tasks, they may not relate to that portion of his mental map which he has presently in mind.

When features of the map conflict irrevocably with a new external observation, the child must either reject the observation, or accept the discomfort of cognitive dissonance (which, unfortunately, he may render painless and therefore unproductive, by "compartmentalization" in the sense of Karplus), or withdraw attention from this particular cognitive area, or else replace the pre-existing cognitive structure by some suitable new one. The way any of us handle this situation separates the realists, the dogmatists, the quitters, and so on. (The literary critic Frederick C. Crews writes: "One cannot demand that a novelist agree with one's politics, only that he show an openness toward reality, a feeling for the variety and complexity of experience." This is surely an important aspect of maturity, in mathematics or anywhere else.[3])

In our own efforts at understanding the learning of mathematics, we have leaned upon Piaget's "assimilation" and "accommodation," upon Tolman's "cognitive maps," and upon pseudo-isomorphic symbol systems in the sense of Leibnitz, Polya, etc.[4]

7. Other Matters.

Among other aspects of Project teaching which we believe to be important are the much-discussed matter of student discovery, the avoidance of culturally-determined answers to questions where answers should be determined by the structure of mathematics ("Two negatives made a positive, just like in English" - but not in French!; also, "A set which is not closed is ________."), and the essential tentativeness and open-endedness of science and mathematics. For further discussion of these subjects, let me refer you to the report entitled The Madison Project's Approach to A Theory of Instruction, which is available from the Project, at Webster College.

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[3] Cf. also Herman Melville's exclamation: "Oh Lord, shall we never be done with growing?"

[4] Cf. Davis, Robert B., "Mathematical Thought and the Nature of Learning: The Madison Project View," Frontiers of Education, American Council on Education, New York, 1963, pp. 79-83.

ACTIVITIES OF THE NATIONAL COUNCIL OF TEACHERS OF MATHEMATICS

Emil Berger

Mathematics Coordinator, St. Paul Public Schools

The author, Emil Berger, is Coordinator of Mathematics for the St. Paul Public Schools and a member of the Board of Directors of the National Council of Teachers of Mathematics. In this paper he reports, briefly, on three projects in which the Council is engaged--the General Mathematics Writing Project, the film project for the in-service training education of elementary teachers, and the production of a yearbook on instructional aids for teachers of mathematics.

As a member of the Board of Directors of the National Council of Teachers of Mathematics, I should like to report on three projects in which the Council is presently engaged. The first of the projects is the Council's General Mathematics Writing Project. The purpose of this project is to produce mathematics text material for non-college bound ninth-grade students with mathematics achievement in the 25-50 percentile range. During the summer of 1963, a group of twelve writers met at the University of Oregon under the direction of Dr. Oscar Schaaf, and produced the preliminary edition of a text entitled Experiences in Mathematical Discovery. The content of the text is organized around nine independent topics which are set forth in as many chapters. The development of the material in each chapter is essentially discovery oriented. Following is a list of the chapter titles:

Chapter 1. Patterns, Formulas, and Graphing Data.
Chapter 2. Arrangements and Selections.
Chapter 3. Intuitive Geometry.
Chapter 4. A New Look at Whole Numbers.
Chapter 5. Ratio, Proportion and Per Cent.
Chapter 6. Learning to Use Directed Numbers.
Chapter 7. Measurement.
Chapter 8. Mathematical Thinking in Geometry.
Chapter 9. Fraction Numbers.

At the present time the preliminary edition of Experiences in Mathematical Discovery is being evaluated. In particular answers are being sought to the following questions:

1. How effective is Experiences in Mathematical Discovery as compared with conventional ninth-grade general mathematics materials?

2. What do teachers think of Experiences in Mathematical Discovery as instructional text material for students of ninth-grade general mathematics?

3. What do mathematicians and educationists think of Experiences in Mathematical Discovery as a text designed for use by ninth-grade students of general mathematics?

4. How readable is Experiences in Mathematical Discovery? (Since Experiences in Mathematical Discovery was written to be read by students and not merely to them, it seems desirable to make some determination as to its readability.)

The second project is the Council's film project for the in-service training education of elementary teachers. In September, 1963, the National Council of Teachers of Mathematics received a grant from the National Science Foundation to produce fifteen 16mm mathematics films, each approximately a half-hour long, and accompanying self-contained text materials. The films are to deal with the number system along the lines of the first three courses recommended for elementary school teachers by the Committee on the Undergraduate Program in Mathematics as preparation for teaching the newer programs in mathematics. An Advisory Committee under the chairmanship of Dr. Julius H. Hlavaty has been established to formulate and carry out policy in connection with the project.

The following designations for the project have been made:

Harry D. Ruderman as Project Director
Joseph Moray as Film Teacher
Reinald Werrenrath, Jr. as Technical Director.

The project is scheduled to be completed by June, 1965.

The third Council project concerns the production of a yearbook on instructional aids for teachers of mathematics. The new yearbook is intended to be a replacement for the Council's eighteenth yearbook, Multi-Sensory Aids in the Teaching of Mathematics, which is now out of print. The new yearbook, for which plans are in progress, is being designed to provide a discriminating appraisal of instructional aids that are presently available and to offer teachers guidance in making appropriate use of desirable instructional aids. The new yearbook will include chapters on such topics as the textbook and classroom viewed as instructional aids, teaching machines, models and mock-ups, projective devices, manipulative devices, supplementary printed material, the use of machines such as computers and computing devices, and the place of exhibits and projects in the school mathematics program.

THE UNIVERSITY OF ILLINOIS MATHEMATICS PROJECT (UICSM)

J. A. Easley, Jr.

University of Illinois

In this brief statement Easley acknowledges the similarity between the University of Illinois Mathematics Project and other mathematics projects. The attempt to eliminate the metalanguage in mathematics instruction, the distinctive feature of the University of Illinois Project, is emphasized.

There is a great deal of commonality among the University of Illinois Math Project, SMSG, Madison Project and other math projects. I would like just to try to characterize briefly some of the distinctive features of the Illinois project. During its first ten years, the Illinois Project developed a level of precision in putting together mathematics texts which permitted talking about the language of mathematics in a well formed metalanguage. Indeed, a number of students who went through the project came to acquire the facility of using the metalanguage as well as the language of mathematics and maintaining precise distinctions between them. From the point of view of project development, one of the advantages of this precision seems to be that mathematicians could agree as to what the concepts were that were being taught and how they were connected together. Recently Max Beberman, the UICSM project director, has decided that there are some distinct limitations to this approach and has launched an effort to develop physical models to accompany every mathematical system.

The former approach provided only physical models which represented operations on numbers, and it elaborated these operations into a mathematical system by symbolic manipulation. The newer approach would provide a physical model at every stage of the game and avoid use of the metalanguage. Traditional mathematics is a mixture of mathematics and talking about mathematics. For example, "Let 'X' represent the unknown product." That statement is in the metalanguage. The traditional UICSM course separated these two levels quite clearly, but the new UICSM is attempting to eliminate the metalanguage as far as use by the student is concerned. These are roughly the pedagogical rules of thumb that guide the development of new materials aimed at enhancing the application of mathematics in the natural and social sciences.

THE CURRICULUM STUDY CENTER AT CARNEGIE INSTITUTE OF TECHNOLOGY

A Project English Program

Robert C. Slack

Carnegie Institute of Technology

Slack describes Project English of the Curriculum Study Center at Carnegie Institute of Technology. The goals, procedural history, recommendations for presenting English, and proposed plans for the project are discussed.

For the past four years Carnegie Tech and Pittsburgh area school systems have been involved in the Advanced Placement program and have cooperated in planning and instituting a twelfth-grade Advanced Placement English course in over 25 schools. Seven of the Pittsburgh area schools are extending their cooperation with Carnegie Tech into the Project English program.

The project of the Curriculum Study Center established at Carnegie Institute of Technology is the development of a sequential and cumulative program in English for able college-bound students in the senior high school (grades 10 through 12).

The program has five major objectives:

1. To develop a composition program for grades 10 through 12 which will lead to the maturation of writing skills in clearly defined, sequential steps.

2. To develop a reading program for grades 10 through 12 which, like the program in composition, will develop sequentially in three years the reading skills essential to excellent work in college.

3. To develop lists of readings, syllabi for composition, teacher's manuals for both reading and composition, and teaching materials for the entire sequence of three courses.

4. To demonstrate the utility of the reading and writing programs by installing them in seven senior high schools of diverse types and sizes in the Greater Pittsburgh area.

5. To evaluate the reading and writing programs through tests given in the cooperating schools.

A long-range goal of the total program is the establishment of a set of standards for high-school English which colleges can use to revise course offerings given to their freshmen so that learning will continue to be sequential and cumulative.

Four members of Carnegie Tech's Department of English (Professors Beekman W. Cottrell, Lois S. Josephs, Robert C. Slack, and Erwin R. Steinberg) and a member of the Department of Psychology (Professor Garlie A. Forehand) are assuming major responsibility for the program.

In the summer of 1962, the cooperating high schools sent two teachers apiece to a four-week Planning Session at Carnegie Tech, and together we defined the main goals of the three-year curriculum and worked out the 10th grade course in detail.

During the school year 1962-63, the 10th grade course was taught in eleven sections in the cooperating high schools. Throughout the year we met with the teachers and revised the course in accordance with what seemed most successful when actually presented in the classroom.

In the summer of 1963, the high school teachers of the 11th and 12th grades engaged in a second Planning Session at Carnegie, and we designed the two courses for these grades. They are now being taught (along with the revised 10th grade course) to over 1000 students in the cooperating high schools.

We have prepared and distributed to the participating high schools a considerable body of textual materials, including readings, daily reading quizzes, unit teaching guides for teachers--as well as the special diagnostic tests given to students at the beginning of the school year.

In the whole program, the Curriculum Study Center has instituted certain teaching procedures which experience and conviction lead us to recommend as the best ways to present the subject of English; these include:

1. Thoughtful discussion of literature, composition, and language, rather than mere recitation of a body of learned facts or generalizations.

2. The reading and examination of literature itself, rather than the memorization of a body of facts or generalizations about literary history or about the lives of writers.

3. The writing of compositions and of essay examinations, which are carefully discussed with the students; these provide the illustrative material for the composition program.

4. The study of the structure, the semantics, and the rhetoric of the English language, rather than a review and a re-review of formal English grammar.

One of the important areas of activity has been the development of a testing program. The Center is developing new tests which attempt better ways to measure learning in the area of English. Also we are concerned with evaluating the new curriculum--both by tests being newly developed and by certain standard tests with established national norms. Dr. Garlie Forehand is in charge of this area of the program.

In the summer of 1964, the Center plans to undertake two activities. The first will involve picked teachers from the cooperating high schools who are invited to assist us to fill in certain gaps in the program. For one thing, we need to review carefully the whole three-year composition program, to spell it out in much greater detail, and to adjust it more closely to the learning rate and the capacity of the students. Also we need to develop in finished form the 12th grade lessons in rhetoric (special emphasis upon how the student can best communicate to the reader for whom he is writing).

Also, in the summer of 1964 we plan to make available small tutorial seminars to which the cooperating schools may send other teachers to become acquainted with the Project English courses and be prepared to teach them. The schools are eager to have more members of their staffs able to step into the program, should the need arise (the need has already arisen in one school).

We are currently submitting a proposal for a research project entitled "Research and Development Participation Program." This project will enable us to modify the curriculum so that it may be extended to a much wider range of students than the top 20% and to modify our materials so that teachers who have not received special training at our Center may present the courses effectively.

TEACHING ENGLISH AS A SECOND LANGUAGE

Gerald Dykstra

Columbia University

The TESL Curriculum Development Center Project at Teachers College is described by Gerald Dykstra. Problems in teaching English as a second language, theoretical considerations, and procedures in developing the project are presented.

TESL is a curriculum development center at Teachers College, Columbia University. TESL stands for Teaching English As a Second Language and as this name indicates, the project is in the area of foreign language teaching.

In foreign or second language teaching, as in many areas, the teacher's role has often been too small. I don't mean that the teacher has taken too little time - just the opposite - the teacher has been doing too much talking and has thereby failed to reach the potential of his role.

Language materials for the teaching of English as a second or foreign language have tended in the last two decades to go in the direction of emphasis on separate sets of materials for each different language background. This emphasis is attended with problems in areas where there are a great many different languages: New Guinea, for example, with 750.

It is difficult to have a separate set of materials for every different language background because 1) we don't have the language descriptions of the background languages, 2) we don't have the people to do the comparisons of English and background languages if we had the descriptions, 3) we don't have the people qualified to write the materials if we had the comparative studies, 4) most countries could not afford to publish and distribute the many different sets of materials if we had the authors, 5) if we had all of that it would be wonderful for many classes, but it wouldn't be especially useful in those situations where the classes are made up of mixed groups.

So much for the practical problems attendant to separate sets of materials. What of theoretical support for a different approach? Linguists are beginning to write about universals in language. Anthropologists have indicated areas of cultural comparability. Linguists, again, would maintain that the essential structural features of English must be maintained for the most part by anyone learning the language. All of this begins to suggest some theoretical basis for a common approach to the preparation of at least some materials in English for a wide range of language backgrounds.

Our project is concerned with preparing materials for elementary school children, the first three years. We are emphasizing the common core and in addition emphasizing international contributions in which we are trying to get the advice and assistance of people from all over the world who have had experience in this field.

We are currently setting the materials up to operate in small groups. This is to avoid having the teacher talk too much. We want the pupils to do the talking and the participating. This may not seem to be a new idea in language teaching. We have long known that small groups seem to provide better situations in the area of language teaching than does the single solid class idea. One difference in these materials is that they are being prepared so specifically for use in small groups that the teacher cannot use the materials in the large single unit class.

The project materials require communication within the small groups. I feel that this is the most significant new contribution of the materials that are being developed in this project. In published materials for the early stages of language learning, language is not elsewhere regularly used as a communicating device for getting information previously unknown to the hearer. It is, at best, used in the pattern practice situation and in pattern practice form together with a situation that children can see. This has been considered to be a meaningful situation. Our contention is that while it may illustrate meaning, it does not make use of a common purpose of language: to inform the hearer and to expect a reaction from him which will be different from that which he might have given before he heard what was said. So the situations here are such that the child from the beginning always has a choice in the things that he may say. The hearer, however, never knows the choices the speaker may make. The speaker, though, is not free to make just any choice. The situation is so set up that he has reason to communicate one or the other of several choices that he may make. There are checks at each point so that the activity will break down if there is failure to communicate an intended message or if the wrong message is selected. This is a responsive environment on a human level rather than in a machine situation.

Preliminary testing indicates that the ideas of actual communication in small groups and children working on their own in a programed sequence show a lot of promise for the field of English as a second language.

The project will develop materials in reading and writing using many of the ideas developed in the early phases of preparing materials for oral work.

THE SOCIAL SCIENCE CURRICULUM STUDY CENTER AT THE UNIVERSITY OF ILLINOIS

Ella C. Leppert

Project Director, Cooperative Research Project,
Social Sciences Curriculum Study Center

Ella Leppert, Project Director of the Social Science Curriculum Study Center at the University of Illinois, describes the development of a sequential social science program in the junior high school. The inductive approach is used throughout the program with an emphasis on logical development of content and compatibility with children's cognitive development.

The Social Science Curriculum Study Center at the University of Illinois is developing the first three courses in a sequential social science program starting with the junior high school. The first or foundation course for the five year sequence introduces students to the persistent problems that have confronted man in all societies over time. The major portion of this first course focuses on ways in which man in our own and in other selected societies has developed institutions for: (1) rearing the young and inducting them into the culture; (2) using and allocating scarce resources to provide goods and services; (3) protecting the members of society and providing public services. A foundation course built around these elements can contribute significantly to students' understanding of how their own and other societies are organized, the dynamic nature of society's social, economic, and political institutions, and wherein a society's institutional arrangements reflect the goals and values of a people.

Beginning with a study of social institutions, the student examines the American family today, using the methods of the social scientist wherever appropriate. Then by examining the American family in an earlier period in time, the colonial family, historical changes are identified and reasons for these changes and the consequences for the family and for society are analyzed. The next step is to introduce the student to another type of family organization, namely, the extended family system of a village in northern India. Students using both primary and secondary sources identify similarities and differences, the reasons for these similarities and differences, and the consequences of this type of institutional arrangement for the Indian family and the Indian society. A third type of family organization, namely, a kinship type such as the Kung people of the Kalahari desert of Sub-Saharan Africa is studied in a similar way. Thus, students examine their own society in the present and in an earlier period of time, and two other societies as models of institutional arrangements for rearing and inducting the young into the culture.

The same general pattern is followed for economic and political institutions starting first with our own society in the present, then in an earlier period in time. Selected models of other societies are introduced to help students sharpen their understanding of similarities and differences, and the dynamic nature of institutions.

Throughout, we emphasize the inductive approach -- confronting the student with selected data, problems, and situations from which he is helped to arrive at basic understandings, concepts, generalizations or principles. Where applicable the student is asked to propose alternative courses of action, to examine probable consequences of the alternatives and to recommend a course of action that seems to be in the best interest of society. The crucial hypothesis in this approach is that when a social science program confronts students with the recurring and persistent problems and questions common to most societies and periods of history, and fosters critical analysis and mature generalization, students will be better able to analyze and deal with disruptive and complex problems that accompany social change.

The materials used in the foundation course draw on the related disciplines of cultural anthropology, history, sociology, political science, social psychology, and economics as sources of concepts and generalizations useful for understanding man, his institutions, and social change.

We are finding that the effectiveness of the inductive approach depends on the sequence in which materials are presented. Consideration must be given to providing a logical content sequence, that is, moving from the concrete to the abstract, from the simple to the complex. At the same time learning activities need to be planned that require of the learner increasing sophistication in such logical reasoning skills as putting things in a series, classifying, separating out variables, seeing relationships among variables, dealing with inverse relationships. Learning experiences in the social sciences can help students develop and reinforce these mental operations that are essential to logical reasoning and to dealing with abstractions.

The dynamic nature of institutions, the causes and consequences of social change introduced in the foundation course are to be developed in greater depth and breadth in the second and third courses. The second course will deal with the limitations as well as the opportunities habitat provides; that man's response to and interaction with the conditions laid down in his habitat in different regions of the world has influenced man's historical development and the evolution of civilizations. Early societies will be studied to identify common factors of development in the evolution of man with the emphasis largely anthropological. Selected early cultures as well as the great regional civilizations will be examined in depth to learn how man developed in these regions, the nature and impact of the cultural contacts among the regional civilizations, and the significance of these contacts for mankind over time. It is planned that approximately three-fifths of the time in the second course will be directed to a study of Western Civilization with major emphasis on the period, 1500 A.D. to the present.

The third course is presently planned as focusing on major non-Western cultures and Latin America. The approach will be to examine, first, the existing conditions largely in terms of political, economic, and social institutions for each of the regions studied, and then, using selected events, explain the historical origins of the present day culture and institutions. Emphasis on the institutional organization and culture of each of the regions will require students to examine values held important by the people of other cultures, to compare and contrast institutional arrangements and values of other regions with each other and with those of their own society. Evidences of change, reasons for and obstacles to change, and the consequences thereof will be examined. It is anticipated that this approach will help students understand that the major cultural regions of the world are basically unique in spite of interaction among them, and that similarities and differences among societies are not accidental but the result of environmental and historical differences.

Materials for the second and third courses will draw heavily from cultural anthropology, geography, history, and area studies.

The procedure followed in the development and dissemination of the three courses includes: (1) planning, in consultation with academic specialists at the University of Illinois, and tryout of the new course in University High School; (2) the first revision of the course together with evaluation instruments and a teacher's guide and tryout in a small number of pilot schools; (3) the second revision of the proposed course and evaluation instruments and tryout in a larger number of cooperating schools; and (4) further analysis of selected data from trial in pilot and cooperating schools and publication of the new course materials.

Looking Back At The Conference

Verne N. Rockcastle, Cornell University

The actual Cornell and Berkeley conference sessions deviated somewhat from the original conference plans. It had been hoped that the conference would suggest specific curricular improvements based on the reports of recent research in cognitive development. With that in mind, selected curriculum specialists or those with an interest in curriculum design were invited to participate in the conference, along with leading psychologists. It was anticipated that Piaget would introduce selected topics, and that subsequent small-group discussions would bring out ways of applying the findings of the psychological researchers to contemporary curriculum problems.

As it turned out, Piaget's forceful presentation of his researches in cognitive development, and the eagerness of the conferees to pursue at some length the major premises and findings of Piaget, curtailed group discussions on curricular applications. However, this did not defeat the purpose of the conference, nor did it lessen the contribution of the conference to curriculum development. Rather, it permitted all the conferees to participate in an open, thorough, and stimulating discussion of the major points of Piaget's presentations, and to listen to and participate in the exchange of views between Piaget and other developmental psychologists who were quick to support certain portions of his theories and to challenge others. If the application of cognitive research to curricular planning and structure was less than originally anticipated, the reports of recent investigations in, and the ensuing discussion of, cognitive development in children exceeded all expectations.

The comments received from the conferees at the close of the conference indicated complete agreement among them that each was challenged to think about the learning process in children, and however complex the process or tenuous our understanding of it, to realize its importance in structuring any formal academic discipline. The cognitive processes under discussion were seen to be basic to all fields represented -- science, mathematics, communication-arts, social studies, and even psychology itself.

In summary, the conference proved to be a real success both because of the intellectual stimulus provided by Piaget, and because of the challenging contributions and vigorous discussions provided by the conferees. I am sure that the ultimate pay-off will come in the intensified efforts of all who attended, or who read this report with understanding and sympathy, to further improve their own educational endeavors, whether they be in formal instruction or in curriculum planning.